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Revision 5
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Criticality Safety Evaluation for the OU 7-70 Glovebox Excavator Method Project

Paul J. Sentieri

**Idaho
Completion
Project**

Bechtel BWXT Idaho, LLC

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Criticality Safety Evaluation for the OU 7-10 Glovebox Excavator Method Project

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**Idaho Completion Project
Idaho Falls, Idaho**

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Revision 5

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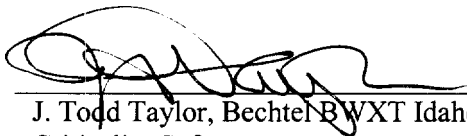
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ABSTRACT

This criticality safety evaluation provides documentation of an analysis of the potential for a nuclear criticality event and identifies controls required to prevent the postulated criticality event from occurring during execution of the Operable Unit 7-10 Glovebox Excavator Method Project. Specifically, the project plans were assessed to identify criticality controls related to the glovebox excavator method to ensure that a criticality hazard will not be likely under credible scenarios. The project will be implemented at the Subsurface Disposal Area within the Radioactive Waste Management Complex at the Idaho National Engineering and Environmental Laboratory.

The composition of the waste matrices expected to be retrieved and repackaged during the project supports the conclusion that the probability of a critical system forming is extremely unlikely. However, a criticality scenario can be postulated because no controls exist on the amount of fissile material present or on the introduction of moderating materials. Therefore, controls will be implemented that prohibit the disturbance of fissile-bearing waste material in the presence of an unsafe amount of moderator (e.g., water).

Revision 5 to this document includes the following changes:

Section 6.5 — Clarified statements about waste forms needing fissile monitoring and other containers in the Packaging Glovebox System including a vacuum.

Section 6.8 — Additions to this section were made to clarify that grouting the empty excavation pit and associated laydown activities are not issues from a criticality safety standpoint.

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ACRONYMS

CSE	criticality safety evaluation
FGE	fissile gram equivalent
FMM	fissile material monitoring
HEPA	high-efficiency particulate air
IDC	item description code
INEEL	Idaho National Engineering and Environmental Laboratory
INTEC	Idaho Nuclear Technology Engineering Center
k_{eff}	effective multiplication factor
MCNP	Monte Carlo N-Particle Transport Code
OU	operable unit
PAN	passive active neutron
PGS	Packaging Glovebox System
PPE	personal protective equipment
RCS	Retrieval Confinement Structure
RFP	Rocky Flats Plant
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area

Criticality Safety Evaluation for the OU 7-10 Glovebox Excavator Method Project

1. INTRODUCTION

1.1 Purpose

This Criticality Safety Evaluation (CSE) documents an analysis of the potential for a nuclear criticality event and identifies controls required to prevent the postulated criticality event from occurring during execution of the Operable Unit (OU) 7-10 Glovebox Excavator Method Project. The project will be implemented at the Subsurface Disposal Area (SDA) within the Radioactive Waste Management Complex (RWMC) at the Idaho National Engineering and Environmental Laboratory (INEEL). The project is located within a small portion of OU 7-10 (Pit 9) of the SDA and the Transuranic Storage Area inside the RWMC. A map of the INEEL showing the location of the RWMC is provided in Figure 1. A graphic representation of the SDA showing an expanded view of the project area is provided in Figure 2.

1.2 Scope

The project plans were analyzed to identify criticality controls related to the glovebox excavator method to ensure that a criticality hazard is not likely under credible scenarios.

1.3 Background

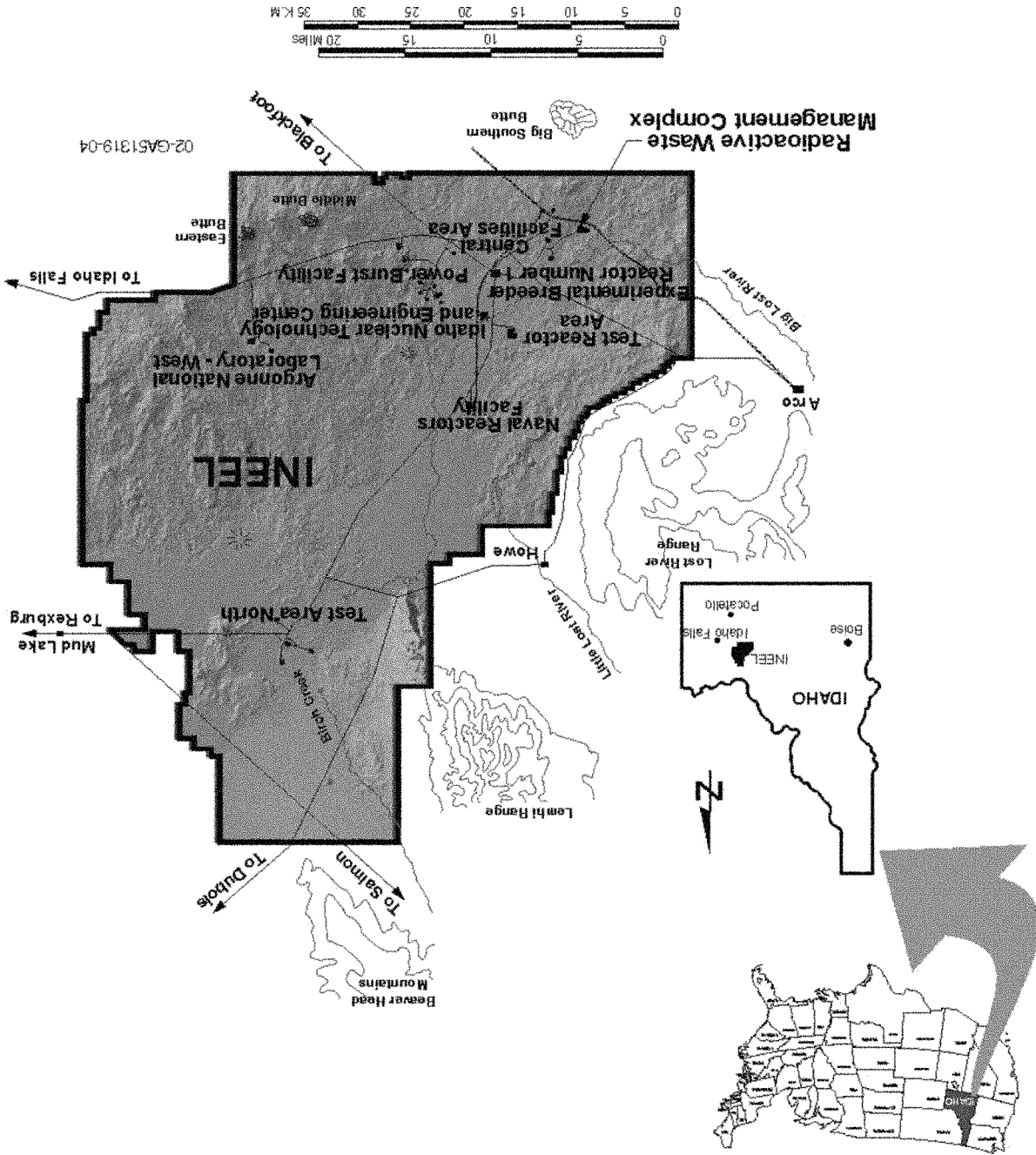
The RWMC was established in the early 1950s as a disposal site for solid low-level waste generated by operations at the INEEL and other U.S. Department of Energy laboratories. Radioactive waste materials were buried in underground pits, trenches, soil vault rows, and one aboveground pad (Pad A) at the SDA. Since 1970, transuranic waste has been kept in interim storage in containers on asphalt pads at the Transuranic Storage Area.

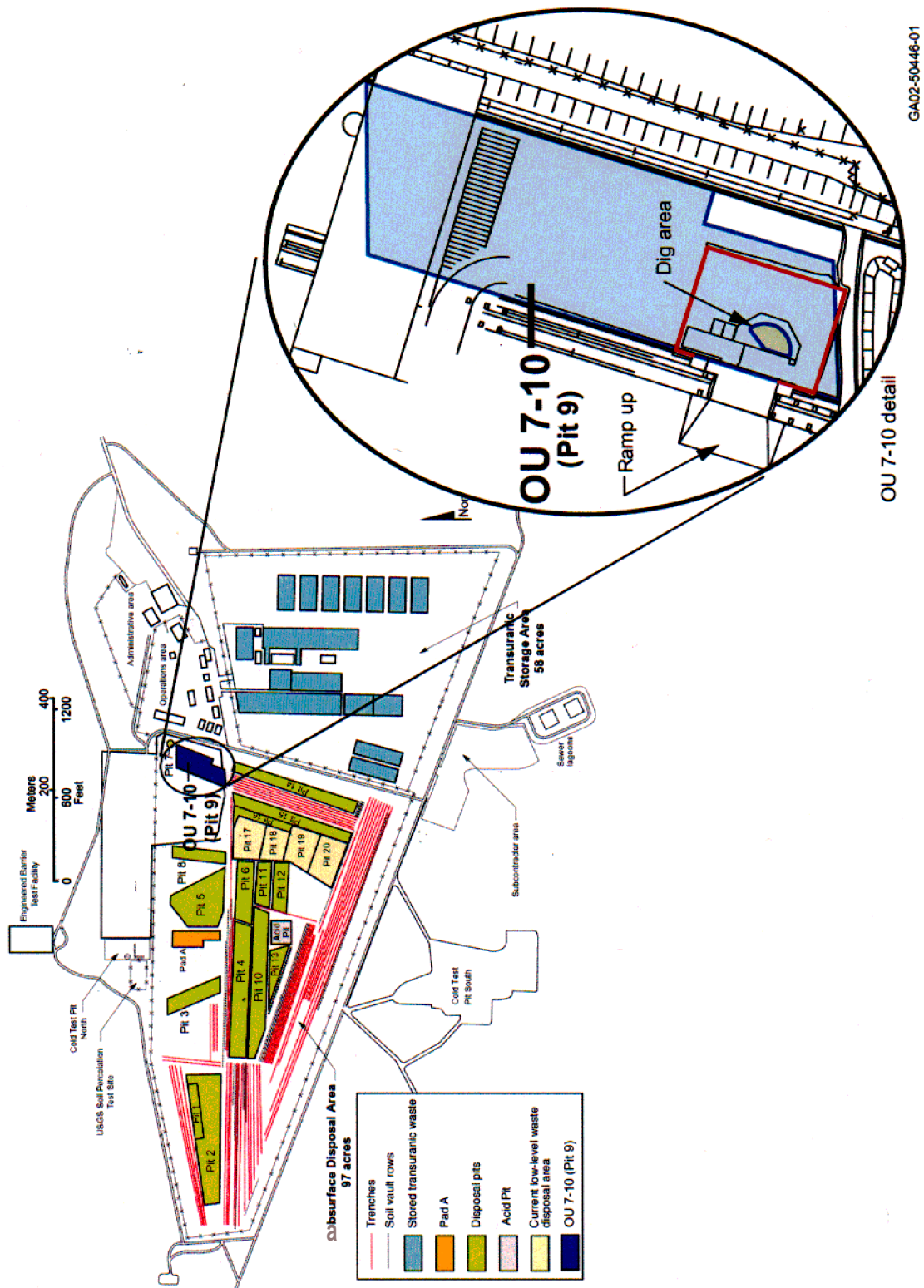
1.4 Objective

The objective of the project is to safely remove and containerize the buried alpha low-level mixed and transuranic waste from an area comprising a 20-ft radius by a 145-degree arc within OU 7-10. The boundary coordinates for the initial probe holes associated with this project are 40 to 80 ft north and 0 to 40 ft east of the southwest monument for a total area of 1,600 ft² (40 x 40 ft). The retrieval area is almost entirely encompassed within this space. The additional area is for use in the construction of a building that will enclose the working area. The majority of the waste buried in OU 7-10 consists of byproducts from the nuclear weapons program plutonium manufacturing process. Most of the original waste was containerized in 55-gal drums, 4 x 4 x 8-ft wooden boxes, and smaller cardboard boxes.

The possibility of causing a criticality during the excavation and retrieval process does exist; however, the probability is extremely unlikely. Process knowledge and archived retrieval reports indicate that the integrity of the waste containers is in various stages of deterioration. The integrity of the containers may range from completely disintegrated to structurally sound.

Figure 1. Map of the Radioactive Waste Management Complex at the Idaho National Engineering and Environmental Laboratory.





GA02-50446-01

Figure 2. Graphic representation of the Subsurface Disposal Area showing an expanded view of the OU 7-10 Glovebox Excavator Method Project area.

Changing the waste environment (e.g., excavating and retrieving an overloaded drum that contains greater than 380 g of fissile mass) may increase the fissile mass density, increase moderation, or create a more favorable geometry for criticality. Changing one or all of these criticality parameters may increase the likelihood of a criticality accident within the project retrieval area. Criticality control parameters for the project are (1) moderation and (2) that the creation of a critical system is extremely unlikely even without controls because the parameters affecting criticality would need to be in near-optimum states. These parameters include the fissile masses necessary to achieve criticality in near-optimized geometry and concentration without the presence of diluent material or some mild neutronic absorbers.

The primary objective of the project is to remove and package 75 to 125 yd³ of waste volume. The project design concept includes remote excavation, handling, and packaging of the retrieved waste from the retrieval area down to the underburden. The waste will be removed from the retrieval area in approximately 2 to 3-ft³ loads, which is the capacity of the bucket used on the backhoe excavator for the project. A simplified overview diagram for the project is illustrated in Figure 3. Further information on details of the operation is contained in “Phase I Operations and Maintenance Plan for the OU 7-10 Glovebox Excavator Method Project” (PLN-678).

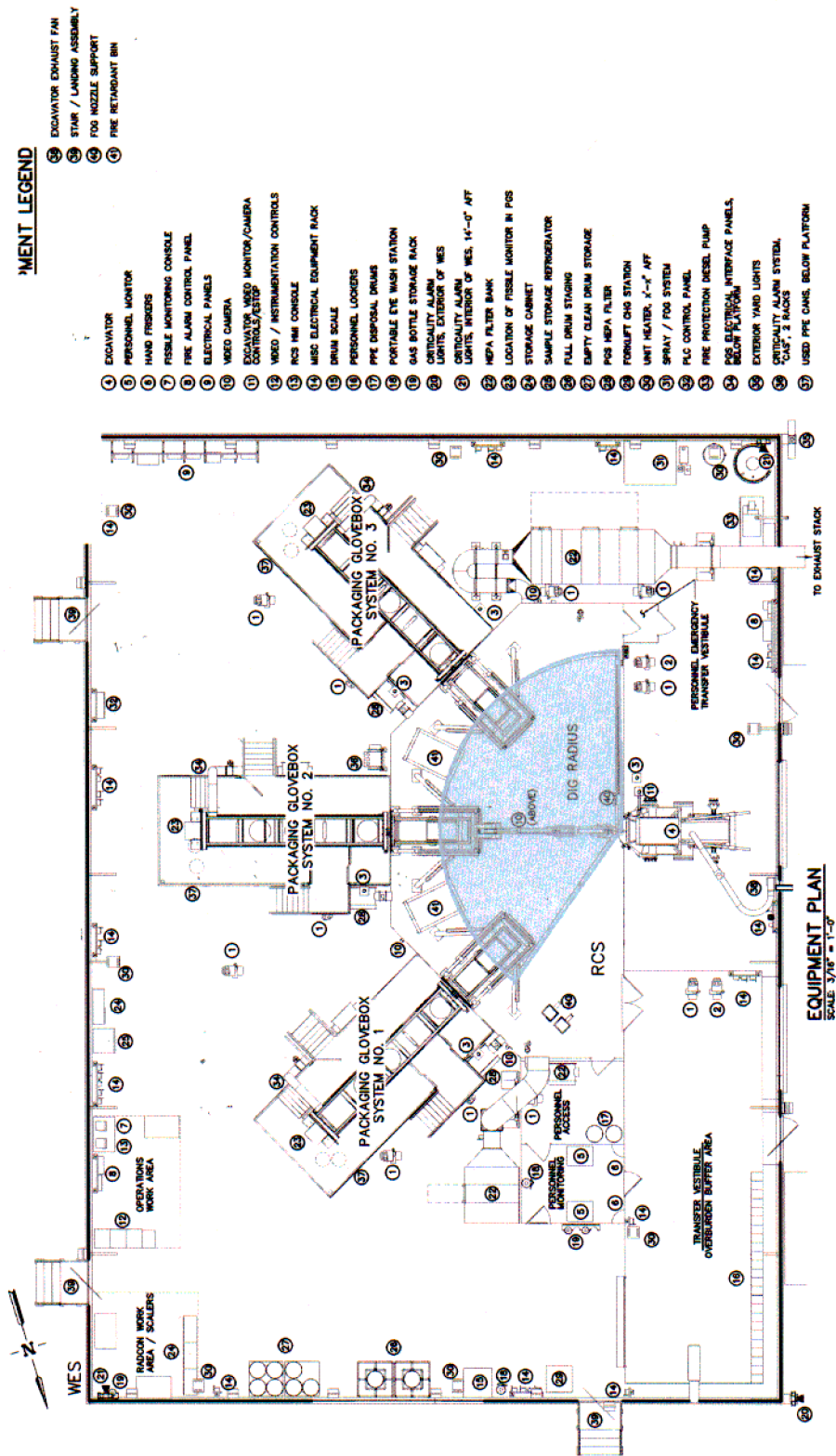


Figure 3. Simplified overview of the OU 7-10 Glovebox Excavator Method Project facilities.

2. DESCRIPTION

In the following subsections, each process of the project and associated criticality implications are described in more detail.

2.1 Waste Content

Studies have been performed to estimate the inventory of waste buried in OU 7-10. A 1999 study^a examined shipping records, manifests, and trailer load lists of the waste that was discarded in the OU 7-10 site. The study identified 10 shipping records that coincide with the project location and concluded that only Rocky Flats Plant (RFP)^b waste is buried in the 40 x 40-ft target area. The study estimated that 1,307 55-gal drums are located in the 40 x 40-ft project area. The taxonomy of the drums is given in Table 1, which also includes the content code that best describes the waste type and the recorded radionuclide inventory. The content codes and radionuclide inventory were taken from the *Content Code Assessment for INEL Contact-Handled Transuranic Waste* (Clements 1982). The mass given in the radionuclide inventory column is the estimated maximum amount, by mass (from the shipping records and manifests), that has been identified in any single drum within OU 7-10.

2.1.1 Plutonium

Plutonium in the project area consists of weapons-grade plutonium; however, the accuracy of historical fissile-loading data cannot be relied on with total confidence. Recent assaying of drums received from the RFP, currently housed in aboveground storage, indicates that a very small percentage of drums exceed 200 g of fissile gram equivalent (FGE). Burial records indicate that waste material expected to be encountered in the waste retrieval area is composed of material that has not been associated with the former suspect overloaded drums in aboveground storage. However, these records do not mean that a drum containing the expected waste materials could not be overloaded. In addition, the records do not exclude the possibility of encountering waste forms that are known to have higher fissile loading. This is based on assay results from aboveground storage operations.

Past assays resulted in 36 overloaded drums (i.e., measuring greater than 380 g FGE) stored in aboveground storage operations at the RWMC. These drums were recently reassayed using a more accurate counting method.

Previous fissile loading measurements were made using the Passive Active Neutron (PAN) System. Three of the counting methods available at Stored Waste Examination Pilot Plant use neutron-counting techniques. These three methods are (1) passive neutron coincidence counting with shielded and unshielded He-3 detectors, (2) passive neutron coincidence counting with only shielded He-3 detectors, and (3) active thermal neutron-induced fission gated totals counting.

Neutron-counting techniques are limited for some waste matrices and certain configurations of fissile materials within the waste. The most significant limitation associated with these suspect overloaded drums was the large alphas-induced uncorrelated neutron output of the waste containers. These large uncorrelated neutron-count rates induce unwanted fissions, increase self-multiplication, and make extraction of signal from noise unreliable.

a. Thomas, R. W., Interdepartmental Memorandum to David E. Wilms, April 16, 1999, "Waste Contents Associated with OU 7-10 Stages I/II Activities in Pit 9," RWT-01-99, INEEL.

b. The Rocky Flats Plant is located 26 km (16 mi) northwest of Denver. In the mid 1990s the Rocky Flats Plant was renamed the Rocky Flats Plant Environmental Technology Site. In the late 1990s, it was renamed again to its current name, the Rocky Flats Plant Closure Project.

Table 1. Taxonomy of drums expected to be located during OU 7-10 Glovebox Excavator Method Project retrieval operations.

Number of Drums	Waste Type	Content Code	Radionuclide Inventory (g)	
379	Series 743 sludge	Code 3: Organic waste (e.g., degreasing agents, lathe coolant, and hydraulic oils).	Plutonium	16.0
260	Combustible material	Code 330: Waste consisting of dry combustible material (e.g., paper, rags, plastics, and surgeons' gloves).	Plutonium	45.0
42	Series 745 sludge	Code 5: Salt residue generated from concentrating and drying liquid waste from the solar evaporation ponds.	Plutonium	0.09 ^a
28	Noncombustible material	Code 480: Nonline and line-generated metal waste (e.g., pumps, motors carts, and power tools).	Plutonium	129.0
27	Series 742 sludge	Code 2: Waste consisting of wet sludge produced from treatment of all other plant radioactive and chemical contaminated waste and further treatment of the first-stage effluent.	Plutonium	8.9
22	Graphite material	Code 300: Graphite molds generated by foundry operations and plutonium recovery operations.	Plutonium	61.0
3	Series 741 sludge	Code 1: Waste consisting of wet sludge produced from treating aqueous process waste (e.g., ion-exchange column effluent, distillates, and caustic scrub solutions).	Plutonium	157.0
2	Series 744 sludge	Code 4: Waste consisting of liquids adsorbed on a cement mixture.	Plutonium	22.7
544	Empty drums	No specific code: Suitable substitute codes may be 950 or 480.	Plutonium	129.0 ^b

a. Plutonium mass is the maximum amount of plutonium found in a drum in accordance with waste shipment records.

b. Plutonium mass is taken from the most conservative waste code (i.e., Content Code 480).

Two Waste Isolation Pilot Plant-certified gamma-ray methods available at the Stored Waste Examination Pilot Plant since April 2002 are (1) passive-absolute gamma-ray counting and (2) transmission-corrected absolute gamma-ray counting.

These gamma-ray system methods do not have the limitations catalogued for the original passive neutron measurements. The gamma-ray counting systems are not affected by the alpha,n interference and are now the available application of choice for high-mass containers at the Stored Waste Examination Pilot Plant.

A summary of contents of the 36 overloaded drums is provided in Table 2, which includes the waste code of the suspect overloaded drums and the original PAN system estimated fissile mass with the more accurate gamma-estimated fissile mass. Waste Isolation Pilot Plant-certified procedures and processes were used to validate these results. As shown by these results, none of the previously overloaded drums exceed 380 g FGE. As shown in Table 2, the previously identified overloaded drums currently in aboveground retrievable storage at the RWMC fall into one of six content code descriptions. These categorizations are given in Table 3.

Table 2. Summary description of 36 suspect overloaded drums identified at the Radioactive Waste Management Complex and new assay results.

#	Drum Identification Number (bar code)	Waste Content Code (IDC)	Original PAN Assay FGE $\pm 1\sigma$ (g)	Fissile Gram Equivalent Mass $\pm 1\sigma$ (g)	Absolute Assay FGE $\pm 1\sigma$ (g)	Fissile Gram Equivalent Mass $\pm 1\sigma$ (g)
1	IDRF004101257	376	385 \pm 139	524	77 f 15	92
2	IDRF004101244	376	483 f 169	652	124 \pm 24	148
3	IDWOOO105403	372	399 \pm 40	439	93 \pm 18	111
4	IDRF004101250	376	798 \pm 288	1,086	164 \pm 31	195
5	IDRF004002686	376	575 \pm 141	716	85 \pm 16	101
6	IDRF004002552	376	379 \pm 86	465	178 \pm 34	212
7	IDRF004002705	376	404 \pm 82	486	228 \pm 44	272
8	IDRF004002614	376	386 \pm 115	501	72 \pm 14	86
9	IDRF004101255	376	367 \pm 61	428	151 \pm 30	181
10	IDRF004101359	376	469 \pm 73	542	183 \pm 38	221
11	IDRF004002133	376	366 \pm 58	424	159 \pm 32	191
12	IDRF004101330	376	410 \pm 95	505	160 \pm 31	191
13	IDRF004101652	376	338 \pm 76	414	86 \pm 17	103
14	IDRF004002540	376	353 \pm 56	409	192 \pm 39	231
15	IDRF004101346	376	355 \pm 70	425	145 \pm 28	173
16	IDWOOO3702123	440	479 \pm 141	620	3 f 1	4
17	IDRF004101295	376	341 f 7 1	412	185 \pm 35	220
18	IDRF004101467	376	273 \pm 109	382	115 f 2 2	137
19	IDRF004101321	376	440 \pm 70	510	156 \pm 31	187
20	IDRF004101324	376	596 \pm 130	726	167 \pm 32	199
21	IDRF004002051	376	388 \pm 61	449	123 \pm 28	151
22	IDRF000302883	440	347 \pm 103	450	126 \pm 25	151
23	IDRF004101604	376	1581 \pm 376	1957	157 \pm 30	187
24	IDWOOO105742	393	481 f 7 9	536	136 f 2 6	162
25	IDRF000302727	409	269 \pm 79	396	80 \pm 40	120
26	IDRF001006049	393	636 \pm 53	689	133 f 2 5	158
27	IDRF004101724	376	422 \pm 5	427	263 \pm 56	319
28	IDWOOO1006329	393	911 f 6 3	974	121 f 2 3	144
29	IDRF004002753	376	571 f 6 0	631	225 \pm 43	268
30	IDRF001006074	393	913 \pm 79	992	112 \pm 22	134
31	IDRF000106094	393	486 \pm 57	543	103 \pm 20	123
32	IDRF000303017	409	460 \pm 83	544	80 \pm 30	110
33	IDRF001006054	393	679 \pm 87	766	94 \pm 18	112
34	IDRF001904055	320	363 \pm 134	497	Footnote b	Footnote b
35	IDWOOO1006330	393	1,243 \pm 117	1,360	143 \pm 27	170
36	IDRF001006051	376	1,046 \pm 92	1,138	103 \pm 20	123

a. See Table 3 for corresponding item description code

b. Value not available. Absolute assay and PAN system are not calibrated for this waste type. Rocky Flats Plant shipping value given as 133 g FGE.

IDC = item description code

PAN = Passive Active Neutron System

Table 3. Content code groupings for identified overloaded drums currently in aboveground retrievable storage at the Radioactive Waste Management Complex.

Item Content Code	Description of Material
320	Tantalum — consists of heavy non stainless steel metals from process operations.
372	Grit — consists of grit (e.g., aluminum oxide and iron fines or pellets) used in grit-blasting operations.
376	Cemented insulation and filter media — consists of filter media removed from various filters, cement added to neutralize acids.
393	Sand, slag, and crucible heels — consists of insoluble residue or “heel” generated from processing magnesium oxide sand, slag and magnesium oxide crucibles contaminated with above discard limits.
409	Glass — consists of sample vials and laboratory glassware.
440	Molten salt —30% unpulverized, waste produced during molten salt extraction process, comprised mostly of chloride residues and plutonium and americium.

2.2 Retrieval Operations

Before the start of retrieval operations, a shoring box will be put in place to line the project area (i.e., 20-ft radius by 145-degree arc). Using the shoring box will ensure that no additional overburden material will fall into the area during retrieval operations. A Retrieval Confinement Structure (RCS) will be constructed over the retrieval area, enclose the retrieval area, and act as the confinement boundary during retrieval activities. These activities will have no impact on the criticality safety aspects of the area.

Overburden will be removed by a remote excavation system (i.e., backhoe). The backhoe may be fitted with a bucket that has volume capacity approximately equal to or slightly larger than the volume of a 55-gal drum. The volume of a 55-gal drum is approximately 7.6 ft³. The removal of the overburden will be monitored from a radiological standpoint to ensure the waste zone is not penetrated during this phase of operation.

2.3 Bulk Waste Retrieval

Bulk waste will be removed from the project area using the excavator (shown in Figure 4). The excavator is a backhoe with changeable attachments for digging and retrieving the waste. If an unsafe amount of free liquid (defined as more than 10 L [2.6 gal]) is visibly evident, then waste retrieval activities will stop until the free liquid is absorbed. However, large amounts of free liquids are not expected in the excavation area based on probing data. The excavator will place the waste zone material into a transfer cart. The transfer cart is essentially a tray to contain and transport the waste material. After the waste material is placed into the transfer cart, it will be moved into the Packaging Glovebox System (PGS). Once in the PGS, the waste will be segregated.

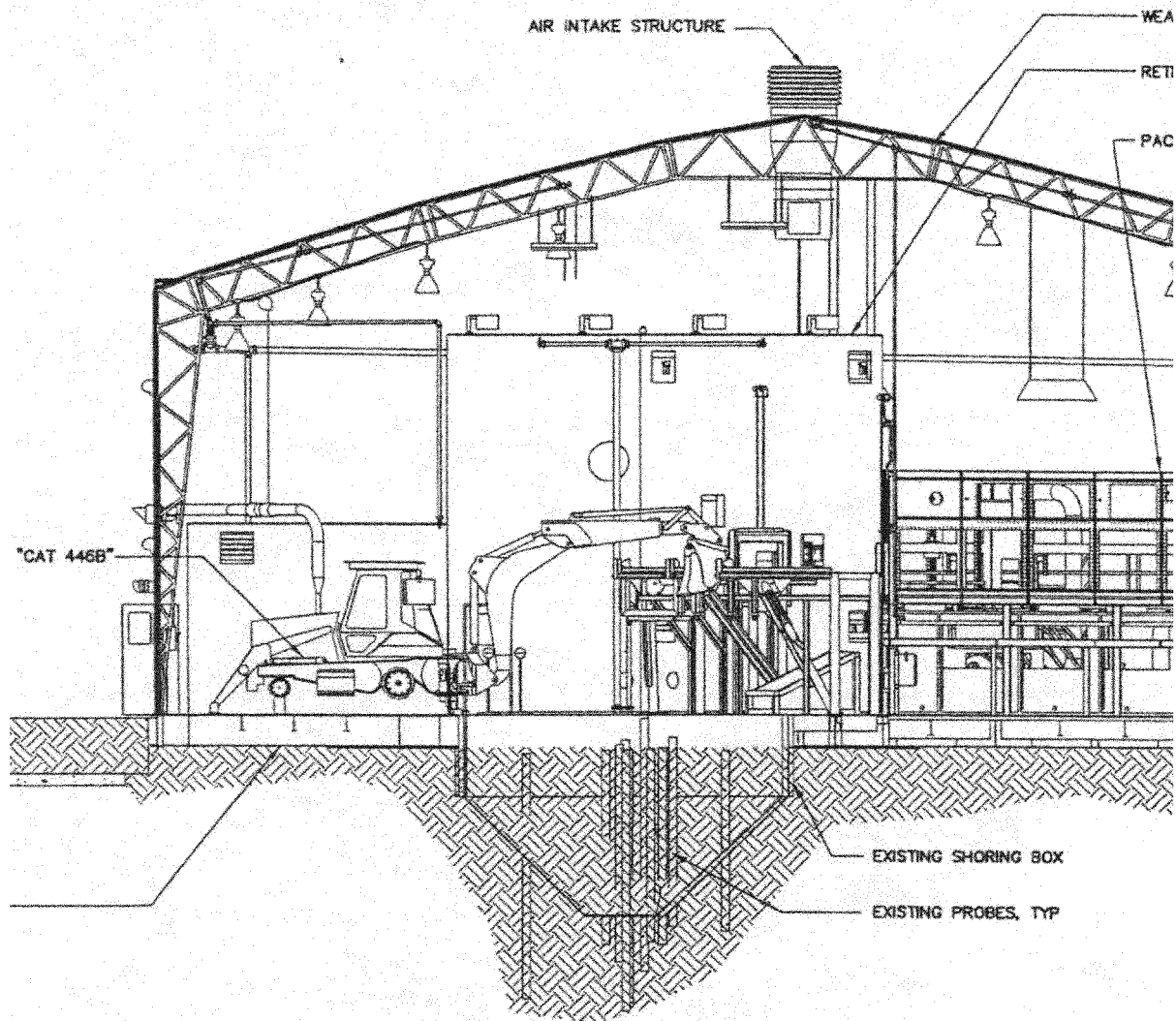


Figure 4. Diagram of excavator and glovebox for the OU 7-10 Glovebox Excavator Method Project.

If the waste comprises soil, sludge, or visibly identifiable combustible materials known from process history to contain low fissile-loading waste, then it will be placed directly into 55-gal drums without being fissile monitored in the PGS. If the material being sorted in the PGS falls within any of the following categories, fissile monitoring will be required:

- Cemented high-efficiency particulate air (HEPA) filters
- High-efficiency particulate air filter media or intact HEPA filters
- Combustibles not distinguishable from HEPA filter media

- Intact graphite molds and large chunks of graphite molds (defined as pieces larger than approximately 2 in. in diameter)
- Unidentified containerized waste that may contain unsafe amounts of plutonium.

Fissile monitoring will be performed before these waste forms are loaded into a drum. Readily identifiable noncombustible materials (e.g., primarily drum remnants and those materials shown to have low fissile loading through the use of process knowledge) will be allowed placement directly into waste drums without being subjected to fissile monitoring.

Drums that contain waste matrices comprising sludge, soil, and certain identifiable combustible material (e.g., personal protective equipment [PPE]) will be loaded directly into drums without the fissile content being monitored in the PGS. This is because these waste forms basically preclude criticality for credible fissile masses because of their composition and constituents. Historical process knowledge indicates these types of waste contain contamination levels, but no appreciable level of fissile material. Waste forms that do not require monitoring before placement in a waste drum are not expected to have fissile loading that exceeds the 380 g FGE limit per drum. Other waste forms of concern will be monitored for fissile content before placement in a drum. This will ensure that the loaded waste drum meets the fissile loading requirement. Therefore, the unassayed waste drums can be stored in a five-high array as long as no more than 500 drums comprise the array (see footnote c). Intact drums uncovered in the waste retrieval area will be broken open in a drum-sizing tray in the bottom of the waste retrieval area. The purpose of this sizing is to ensure compliance with the 350-lb structural limit on the transfer cart. The drum demolition tray is shown in Figure 5.

2.3.1 Packaging Glovebox System

Three gloveboxes are attached to the RCS (see Figure 6). Each glovebox will be constructed with a steel frame, fire-resistant safety glass panels, glove ports with gloves and safety covers, access panels, a rail-mounted transfer cart, operator work platforms, and HEPA filter inlets for the ventilation system. Several packaging stations will be included in each glovebox for loading waste into 55- and 85-gal drums. Each packaging station will be accessed through a port in the bottom of the glovebox. A fissile material monitoring (FMM) system (SPC-355, 360) will quantify the fissile content of unknown and suspect items. It can be used to monitor drum loading of this material to ensure that fissile drum limits are not exceeded. Each glovebox will have a FMM system.

Retrieved waste material will be sent to the PGS in transfer carts. The cart volume is large enough to contain one intact drum. However, operationally, most loads will be limited to approximately one-third the volume of a 55-gal drum.

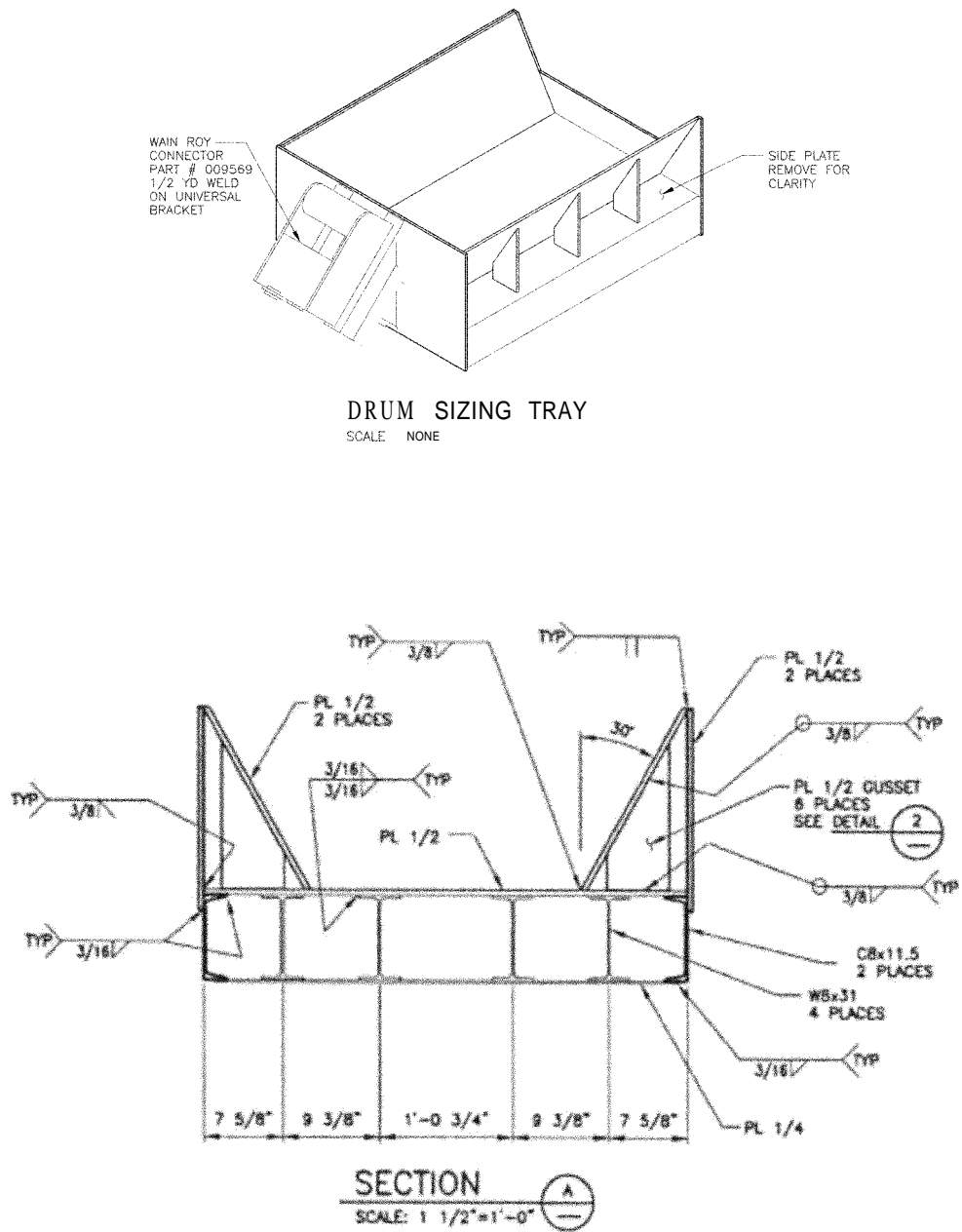


Figure 5. Diagram of drum-sizing tray for the OU 7-10 Glovebox Excavator Method Project.

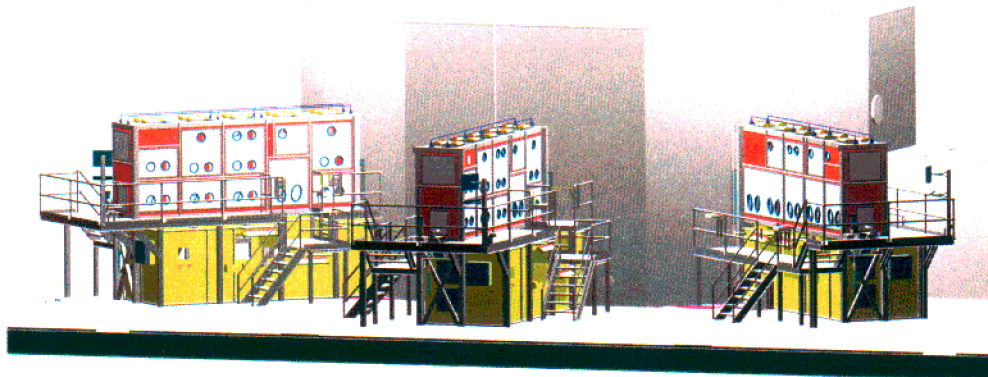


Figure 6. View of the Packaging Glovebox System for the OU 7-10 Glovebox Excavator Method Project,

2.4 Material Evaluation in the Packaging Glovebox System

After the waste material has been transferred into the PGS with the transfer cart, an evaluation will be made of the type of material present. Materials of concern to criticality safety include cemented HEPA filters, filter media, intact HEPA filters, combustibles not distinguishable from HEPA filter media, and unknown containerized waste materials that could potentially contain unsafe plutonium masses. Other materials (e.g., intact graphite molds and graphite pieces of molds larger than approximately 2 in. in diameter) need to be assayed based on probing data and the historically higher fissile content in these waste forms. Based on past process knowledge, some waste matrices can be packaged directly into drums without monitoring the fissile content as the waste drums are loaded. These materials include sludge, soils, and certain combustibles readily identifiable as having low reactivity from past process knowledge.

The fissile mass of other material (e.g., filter media, intact HEPA filters, and unidentifiable combustible material that could include some cellulose material) will require monitoring while these matrices are being loaded into waste drums. Monitoring will be performed to identify and prevent unsafe fissile masses from being loaded in a drum. This will ensure that the fissile loading limit per drum will not be exceeded. The creation of overloaded drums in this retrieval process is highly undesirable. Recovery from overloaded drums (i.e., drums containing more than 380 g FGE) containing the aforementioned waste material would require implementation of rigid controls that would prove difficult from an operational standpoint.

2.5 Storage of Loaded Drums

Drums containing waste matrices comprising sludge, soil, and certain identifiable combustible material (e.g., PPE) will be loaded directly into drums without the fissile content being monitored in the PGS. In some cases, waste forms basically preclude criticality because of composition and constituents. In other cases, historical process knowledge indicates no appreciable amounts of fissile material are present in these waste forms. Waste forms that do not require monitoring before placement in a waste drum are not expected to have fissile loadings that exceed the 380 g FGE limit per drum. Other waste forms of concern will be monitored for fissile content before placement in drums. This will ensure that loaded waste drums meet the fissile loading requirement. Therefore, the unassayed waste drums can be stored in a five-high array as long as no more than 500 drums comprise the array.

2.6 Sampling

The current Field Sampling Plan (Salomon et al. 2003) calls for the collection of soil and sludge samples from the waste zone for waste characterization. The samples will be placed in nominal 250-ml jars, assayed by the fissile monitor, and removed from the glovebox three at a time by using a stainless steel french can. The french can will be placed in an approved shipping container and transferred to analytical laboratories at the Idaho Nuclear Technology Engineering Center (INTEC) for analysis. Although there is a low probability that a small piece of waste with concentrated plutonium may be in the sample, the fissile monitor will identify this material before transfer out of the glovebox. A 250-mL sample containing soil equates to approximately 380 g, assuming a soil density of 1.46 g/cm^3 (Callow et al. 1991). Samples from the waste zone will be fissile monitored before transportation to analytical laboratory facilities to determine fissile content. The purpose of this is to ensure compliance with applicable transportation requirements.

c. Nielsen, J. W., 2002, "Criticality Safety Evaluation for Finite Arrays of Drums Containing up to 380 g of Pu-239 RWMC," INEEL/INT-02-00973, Rev. 0, INEEL, September 2002.

After the waste has been removed from above the underburden, the project plans to take several core samples of soil. These samples will be contained in nominal 2-in. diameter cores between 24 and 54 in. long. Each sample will be shipped individually in an approved shipping package and transferred to analytical facilities at INTEC. Fissile material in the underburden will only occur as a contaminant and there are no known pathways for significant unsafe quantities of plutonium to migrate to and concentrate in the underburden. Even if plutonium is in the underburden, there is no credible criticality scenario (see Section 6.6). There is no need to require fissile monitoring or assaying of the underburden core soil samples for criticality safety.

3. REQUIREMENTS DOCUMENTATION

No special documentation requirements are applicable to this CSE.

4. METHODOLOGY

Calculational models were developed for this evaluation. These calculations use the Monte Carlo N-Particle Transport Code (MCNP) computer program (RSIC 1997) to assess the criticality potential associated with OU 7-10 Glovebox Excavator Method Project activities. The MCNP Program and the validation of the MCNP code are described in this section.

4.1 Description of Method

The MCNP is a general-purpose code for calculating the time-dependent continuous-energy transport of neutrons, photons, and electrons in three-dimensional geometries. The MCNP code is used for many applications (e.g., nuclear criticality safety, radiation shielding, fission heating, and many other nuclear-related topics). This code was used in this analysis to determine the calculated effective multiplication factor (k_{eff}). The k_{eff} is a measure of the ability of a finite system to sustain a nuclear chain reaction and is defined with the following criteria:

- Supercritical if $k > 1$
- Critical if $k = 1$
- Subcritical if $k < 1$.

The MCNP Program was performed on a Hewlett-Packard Series 9000 workstation using the HP-UNIX 10.20 operating system. The MCNP-4b2 used the ENDF/B-V cross-section data to calculate the results. The workstations are verified and validated in accordance with the INEEL *Software Quality Assurance Plan for MCNP4A and MCNP4B2*.^d

The analyzed system contained in this report consisted of plutonium dispersed in various waste matrices including soil, graphite, and magnesium oxide. The geometry of the systems evaluated consisted of waste materials and plutonium in cylindrical form (drums), spherical form (optimized systems), and rectangular form (transfer cart).

No critical experiments exist that exactly match the types of systems evaluated. However, modeling critical experiments encompassing the parameters evaluated can validate the various models. These parameters include material composition, moderation conditions, reflection conditions, and spectral neutron energy ranges.

Validation for these calculations requires experiments consisting of moderated plutonium solution systems and plutonium combined with silicon and graphite.

A separate report was completed that evaluated critical plutonium and silicon configurations.^e Experiments consisting of plutonium fuel rods intermixed in a triangular lattice with SiO_2 rods were performed in Obninsk, Russia, in 1998 and 1999. A complete detailed description of the critical configurations can be found in *Critical Experiments with Heterogeneous Compositions of Highly Enriched Uranium, Silicon Dioxide, and Polyethylene* (Tsiboulia et al. 2000).

d. Montierth, Leland M., 2000, *Software Quality Assurance Plan for MCNP4A and MCNP4B2*, INEEL/INT-98-01140, Rev. 0, WEEL.

e. Nielsen, J. W., 2002, *Validation of Uranium and Plutonium Silicon Dioxide Experiments*, INEEL/INT-02-01106, Rev. 0, WEEL.

A brief description of the experiments follows. Ten different rod types were used in the plutonium experiments. Each of the rods consisted of a stack of various discs or pellets of various materials. These materials included plutonium metal canned in stainless steel, silica pellets, polyethylene pellets, stainless steel pellets, and boron carbide pellets. Each of the rods contained a combination of these pellets in a stacked configuration. The rods then were combined to create a critical system. The fuel tubes were arranged in a hexagonal array with a 5.1-cm pitch.

The experiments were modeled as described above. Calculated results for experiments using the ENDF/B-V cross-section library are provided in Table 4. Experiment ratios for WX and Si/X also are presented in the table. The H/Pu ratio varied from 0 to 35 while the Si/Pu ratio varied from 23 to 42. The calculated neutron energy spectrum for these experiments indicates that the energy of the neutrons causing fission is primarily in the intermediate range (i.e., 0.625 keV to 100 keV) to fast (i.e., more than 100 keV). The average calculated k_{eff} for these experiments is 1.0075 ± 0.0003 .

Table 4. Calculated results for the plutonium experiments.

Case Name	H/Pu	Si/Pu	$k_{\text{eff}} \pm \sigma$
BFS-8 1/1	0	23.4	1.0001 ± 0.0006
BFS-81/1A	0	23.4	0.9987 ± 0.0008
BFS-8 1/2	2.8	23.4	1.0055 ± 0.0008
BFS-8 1/3	5.6	23.4	1.0089 ± 0.0008
BFS-8 1/4	35.2	41.6	1.0178 ± 0.0008
BFS-8 1/5	35.2	41.6	1.0164 ± 0.0008
Average: ^a $k_{\text{avg}} = \Sigma (k_i/\sigma_i^2) / \Sigma (1/\sigma_i^2)$, $\sigma_{\text{avg}} = (1/\Sigma (1/\sigma_i^2))^{1/2}$			1.0070 ± 0.0003
a. ICSEBP 2000.			

Performance of this code package and computational platform is well demonstrated for plutonium solution systems. Two cases were modeled that consisted of plutonium nitrate in a bare and reflected spherical configuration. A complete description of these cases can be found in Carter and Wilcox (1999). The MCNP listings associated with these cases can be found in Appendix A.

The first case evaluated consisted of a 19.608-cm diameter radius spherical shell containing plutonium nitrate. The thickness of the 304-L stainless steel shell is 0.1219 cm. The spherical shell in this case was not reflected. The plutonium nitrate solution had a concentration of 39.0 g/L plutonium. The hydrogen to plutonium (H/Pu) ratio was approximately 700 for this case. The calculated $k_{\text{eff}} \pm 1\sigma$ for this case was 1.0134 ± 0.0013 .

The second evaluated case consisted of the same spherical configuration except this case was reflected by a 30-cm water reflector. The concentration of the plutonium nitrate was 25.2 g/L plutonium, with the sphere being full to a height of 18.754 cm above the centerline of the sphere. The H/Pu ratio was approximately 1,100. The calculated $k_{\text{eff}} \pm 1\sigma$ was 1.0154 ± 0.0010 .

The last set of evaluated cases consisted of PuO_2 /polystyrene and reflected by plexiglass. Experiments were performed at Hanford between 1963 and 1970. The experiments consisted of cubes of PuO_2 /polystyrene reflected by plexiglass plates. Twenty-nine experiments were performed with various configurations, concentrations of plutonium, and plutonium enrichments.

The cubes were approximately 2 x 2 x 2 in. The cubes were stacked on a split table critical assembly. The two halves of the assembly were brought together and the neutron multiplication determined using proportional counters. Some cubes were cut in the axial direction to allow flexibility in obtaining a critical height. The final critical configuration consists of a rectangular block of PuO₂/polystyrene reflected on all six sides by plexiglass. The H/Pu ratios ranged from 5.87 to 65.4 with the C/Pu ratios varying from 5.86 to 64.4. A more detailed description of these experiments can be found in an internal report (Justice 2000) that discusses validation of calculations containing highly enriched uranium combined with graphite and plutonium distributed in polystyrene. The results from these cases can be found in Table 5.

Table 5. Calculated results for the PuO₂/polystyrene experiments.

Case Name	$k_{\text{eff}} \pm \sigma$
Case 6	1.0170 ± 0.0009
Case 7	1.0177 ± 0.0008
Case 8	1.0173 ± 0.0007
Case 9	1.0193 ± 0.0008
Case 10	1.0285 ± 0.0010
Case 1	,0270 ± 0.0010
Case 2	,0247 ± 0.0010
Case 3	,0233 ± 0.0009
Case 4	,0275 ± 0.0010
Case 5	1.0256 ± 0.0009
Case 16	1.0214 ± 0.0010
Case 17	1.0045 ± 0.0009
Case 18	1.0088 ± 0.0008
Case 19	1.0051 ± 0.0007
Case 20	1.0056 ± 0.0008
Case 21	1.0072 ± 0.0009
Case 22	1.0101 ± 0.0008
Case 23	1.0054 ± 0.0009
Case 24	1.0054 ± 0.0008
Case 25	1.0069 ± 0.0017
Case 26	1.0081 ± 0.0009
Case 27	1.0086 ± 0.0008
Case 28	1.0091 ± 0.0009
Case 29	1.0110 ± 0.0010
Average: k_{avg} $= \Sigma (k_i / \sigma_i^2) / \Sigma (1 / \sigma_i^2), \sigma_{\text{avg}} = (1 / \Sigma (1 / \sigma_i^2))^{1/2}$	1.0138 ± 0.0002

a. ICSEBP 2000.

As shown by the results of these validation experiments, no bias caused by calculational methodology is warranted.

5. DISCUSSION OF CONTINGENCIES

The double contingency principle as stated in U.S. Department of Energy Order 420.1, "Facility Safety," is defined below.

The double contingency principle shall be used as a minimum to ensure that a criticality accident is an extremely unlikely event. Compliance with the double contingency principle requires that two unlikely, independent, and concurrent changes in process or system conditions occur before a criticality accident is possible.

Consideration has been given to project scenarios that could have an impact on criticality safety. Requirements of the double contingency principle have been met for those proposed operations in the OU 7-10 Glovebox Excavator Method Project and the project is covered under a formal safety analysis basis. Reliance on administrative controls will be adequate because such a large margin of safety is inherent in these types of waste systems, which by the nature of the waste material would make achieving a critical state extremely unlikely.

5.1 Waste Retrieval Operations

Contingency analysis for the digface surface area maintains criticality safety by controlling operations in the presence of an unsafe amount of moderating material. An unsafe amount of liquid is defined as more than 10 L (2.6 gal) of free liquid in a configuration deeper than 2.6 in. If the solution is less than 2.6 in. deep, then the system will remain safely subcritical. Table 6 contains the contingencies for waste retrieval operations.

Table 6. Contingencies for waste retrieval operations.

Scenario Number	Scenario Description	Failure or Barrier	Additional Information
1	Excavation of an overloaded drum while an unsafe amount of free liquid is present.	(1) Violation of administrative controls prohibiting retrieval operations if an unsafe amount of free liquid is encountered during retrieval operations. (2) Achievement of a favorable criticality configuration that is required to form a critical system.	Conditions that are required for a criticality to occur include sufficient mass, optimal moderation, favorable geometry, and insufficient diluent in the waste.
2	Activation of the deluge system either manually or through failure of a valve during excavation operations when an unsafe amount of fissile material is disturbed.	(1) Violation of administrative controls prohibiting retrieval operations if an unsafe amount of free liquid is introduced during retrieval operations. (2) Achievement of a favorable criticality configuration that is required to form a critical system.	Conditions that are required for a criticality to occur include sufficient mass, optimal moderation, favorable geometry, and insufficient diluent in the waste.

5.1.1 Scenario One

The first scenario involves excavation with an unsafe mass of fissile material being disturbed in the waste retrieval area while an unsafe amount of moderating material is present. If an unsafe amount of moderating material is present in the fissile-bearing waste material, a critical system could be postulated. The fissile mass would need to be in a configuration that would allow for near optimum moderation, lack of neutronic poisons or diluents in the system, and near-optimum geometrical configuration of the fissile material and reflection that decrease neutron leakage from the system. Burial records indicate limited amounts of fissile material are present in the waste buried in the retrieval area. However, these records cannot be relied on to provide complete assurance that an overloaded fissile material drum will not be discovered. Therefore, controls will be instituted to ensure that a criticality does not occur.

The first contingency is an administrative control prohibiting fissile material handling in the presence of an unsafe amount of free liquid. By prohibiting material disturbance in the presence of the defined unsafe amount of free liquid, criticality is precluded. This will ensure that the system remains undisturbed until absorbent material can be added to eliminate the presence of free liquid.

The second contingency, which is unlikely, is the formulation of a system containing unsafe fissile mass with near-optimum moderation, ideal geometric configuration, lack of neutronic poisons or diluents, and no neutron leakage.

5.1.2 Scenario Two

The second scenario is similar to the first except that the moderating material would be introduced by the deluge system. In this case, the unsafe mass of fissile material would have to be disturbed after the deluge system had been activated and the unsafe amount of moderator introduced. Again, the first contingency would be an administrative control that prohibits disturbance of fissile waste if an unsafe amount of moderator is added during waste retrieval operations. This would ensure the system remains as configured until adsorbent material can be added to the system to eliminate the presence of free liquid.

The first contingency is an administrative control that prohibits fissile material handling in the presence of an unsafe amount of free liquid. This would ensure the system is undisturbed until absorbent material can be added to eliminate the presence of the free liquid. By prohibiting the disturbance of material in the presence of the defined unsafe amount of free liquid, criticality is precluded. This restriction eliminates the motive force needed to create a homogeneous slurry of fissile material and moderator that could lead to an unsafe configuration. The actual introduction of the moderating material is of concern, but other factors need to occur (e.g., optimum distribution and full reflection), as delineated in the second contingency.

The second contingency, which is unlikely, is the formulation of a system containing unsafe fissile mass with near-optimum moderation, ideal geometric configuration, lack of neutronic poisons or diluents, and no neutron leakage.

5.2 Packaging Glovebox System

Contingency analysis for the PGS contains criticality safety margins that are maintained by (1) controlling operations in the presence of an unsafe amount of moderating material and (2) limiting the fissile mass placed into a waste drum for certain waste matrices through the monitoring process (see Table 7).

Table 7. Contingencies for the Packaging Glovebox System.

Scenario Number	Scenario Description	Failure or Barrier	Additional Information
1	Waste forms of concern containing more than 380 g FGE in the PGS in the presence of an unsafe amount of free liquid.	(1) Failure to monitor fissile mass of waste material of concern as it is loaded into the waste package. (2) Violation of administrative controls prohibiting operations in the PGS if an unsafe amount of free liquid is encountered in the PGS.	Introduction of unsafe amounts of moderating material through activation of the PGS fire suppression system. Conditions that are required for a criticality to occur include sufficient mass, optimal moderation, favorable geometry, and insufficient diluent in the waste.

FGE = fissile gram equivalent
PGS = Packaging Glovebox System

5.2.1 Scenario Three

The third scenario consists of unsafe fissile mass in the presence of an unsafe amount of moderating material. However, the scenario is postulated in the PGS. The scenario considers activation of the PGS fire suppression system, which is a mist-type system, introducing an unsafe amount of moderator in the presence of an unsafe fissile mass. As waste is retrieved, it is brought into the PGS and evaluated. If the waste comprises soil, sludge, noncombustible, or visibly identifiable combustibles, it can be placed into waste containers before being fissile monitored. These types of waste matrices comprise materials that preclude criticality because of their form and composition. Other waste material (e.g., filter media, graphite material and nonidentifiable combustibles) is monitored in the PGS as the waste containers are being loaded. This is accomplished by using a fissile monitoring device on small portions of waste material before loading and then tracking the fissile material content placed into a drum. The purpose of the FMM is twofold. The first is to ensure the waste drum is not overloaded with more than of 380 g of fissile material, thus precluding the formation of a critical system within a single drum. The second purpose is to ensure that the eventual storage arrays of drums are safe.

The first contingency is the requirement to monitor the fissile mass of waste matrices of concern before loading into the drum waste packages. Calculational models were developed to show that the fissile mass necessary to achieve a critical configuration in the transfer cart is not credibly expected as part of this retrieval effort. The fissile material specimen container is limited in volume to 5-1/2 gal, thus limiting the amount of waste that can be placed into it. It is not credible to get waste in the specimen container with the optimum conditions required for criticality. The volumetric limit on the specimen container would allow the collection of greater than 10 L (2.6 gal) of free liquid. However, the amount of waste material present in the FMM specimen container is small and the configuration is controlled. If the specimen container were to collect more than 10 L (2.6 gal) of free liquid, the control prohibiting the

disturbance of this material would be in effect and preclude stirring up material that could possibly create an increase in reactivity within the system. Therefore, the most likely location to postulate the formation of a critical system is in a waste drum loaded with waste matrices of concern. Therefore, matrices of concern will be monitored for fissile loading before placement in a drum. Additionally, waste forms requiring monitoring can only be placed into the FMM specimen container before monitoring. This requirement eliminates the need to control the volumes of other containers within the **PGS**.

The second contingency is an administrative control that prohibits fissile material handling in the presence of an unsafe amount of free liquid. This will ensure the system remains as configured until absorbent material could be added to the system to eliminate the presence of the free-flowing moderator material. By prohibiting the disturbance of material in the presence of the defined unsafe amount of free liquid, criticality is precluded. This restriction eliminates the motive force needed to create a homogeneous slurry of fissile material and moderator that could lead to an unsafe configuration.

6. EVALUATION AND RESULTS

The methods of criticality control evaluated for the OU 7-10 Glovebox Excavator Method Project are outlined in the following sections and results from the analysis are presented. The corresponding computational model listings used in support of this analysis are presented in Appendix A.

6.1 Assumptions

Assumptions used in the analysis are listed below:

- Amount of fissile mass present is not known with complete certainty
- Geometry, as a condition of the fissile system, cannot be controlled in the waste retrieval area
- Fire in the PGS is an anticipated event

As stated previously, the fissile content within the excavation area has been estimated to be low, but some uncertainty with these estimates and the records supporting these estimates exists. Therefore, an underlying assumption is that the fissile content in the excavation area is not known with certainty.

Additionally, containers that held the fissile material are expected to be in a degraded state. Therefore, the containers cannot be relied on to provide geometrical configuration control for the fissile material.

The third assumption, which is conservative, will be stated in the final documented safety analysis as an anticipated event. The pyrophoric nature of some compounds in the waste, along with the combustible material loading and uncertainties in the waste, leads to this conclusion.

6.2 Criticality Control

The criticality control philosophy for the project is taken from ANSI/ANS-8.1, "Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors" (ANSI 1998). The nuclear criticality standard (ANSI 1998) designates criticality control by geometry (e.g., passive engineered controls) as the preferred method. An example of geometrical control is the limited height of the transfer cart. In situations where control by geometry is not practical, control by administrative measures may be considered. In addition, the design and operation of facilities that process material outside of reactors must follow the double contingency principle described in ANSI/ANS-8.1 (ANSI 1998). In accordance with the double contingency principle, two separate, independent, and unlikely changes in process or system conditions are required before a criticality accident can occur.

Criticality concerns associated with these operations include encountering an overloaded drum in the waste retrieval area. The control associated with this concern will be to not allow disturbance of material in the waste zone in the presence of more than 10 L (2.6 gal) of free liquid.

A similar concern will exist in the PGS system if an unsafe fissile mass is brought into the PGS from the waste retrieval area. A similar control is associated with operations within the PGS. This control will require that operations stop and no further processing of waste material be allowed within the glovebox if more than 10 L (2.6 gal) of free liquid is present. Before operations are resumed, free liquids must be absorbed or removed from the system.

Another criticality concern associated with this operation includes placement of an unsafe fissile mass into a waste drum in the presence of certain waste forms (e.g., HEPA filter media). Certain waste forms could have potentially high-fissile loading based on past process history. Recent reassay of

36 suspect overloaded drums determined that none of the 36 drums exceed an FGE loading of 380 g (INEEL 2003).

Placement of the physical waste form directly into a drum, without assessment of the fissile content, could result in creating an unsafe condition where addition of moderating material could lead to a postulated critical configuration. Because moderator (e.g., water) will not be excluded from the glovebox, certain waste forms will be required to be fissile monitored and fissile material will be tracked as the drum is filled. This will control the amount of material present in the drum for these certain waste matrices, thus precluding a critical system from forming in the event of flooding.

6.3 Process Areas

Process areas are broken into the three distinct areas listed below:

- Waste retrieval area
- Packaging Glovebox System
- Drum storage area.

Each area and the associated criticality controls are discussed in more detail in the following subsections.

Various parameters that influence whether a system can achieve a critical state are listed below:

- Presence of fissile mass
- Presence of moderator
- Geometrical configurations
- Presence of diluents or neutronic absorbers
- Reflection conditions surrounding the systems
- Concentration of fissile material and nature of their distribution in the system

Most of these factors would require optimization in some combination to achieve a critical system constructed within reasonable constraints. As deviation from optimum conditions occurs, the reactivity of the systems decreases dramatically. In addition, as previously stated, an unsafe amount of moderator would be necessary to form a critical system in these waste forms.

One of these parameters is not controllable: the presence of fissile mass in the waste retrieval area, along with the existing geometry of the material. The fissile system may be reflected because this system would exist within soil. Diluent materials that also act as neutronic absorbers are known to exist in the waste material. The quantity and distribution of these materials cannot always be relied on to guarantee that the system will remain in a subcritical state. However, in every case, an unsafe amount of moderator would be required to achieve a critical system.

The expected fissile mass associated with most of the expected waste forms in the waste retrieval area is low (i.e., less than 200 g FGE per buried drum). Reassay information for the suspect drums reduces the likelihood of encountering an overloaded drum, but does not exclude the possibility.

6.4 Waste Retrieval Operations

6.4.1 Waste Retrieval Operations Area

Disturbing an overloaded drum and creating an unfavorable configuration during the excavation and retrieval process is possible. Process knowledge, archived retrieval reports, and visual probes indicate that waste containers are in various stages of deterioration. The integrity of the containers may range from being completely disintegrated to structurally sound. Changing the waste environment (i.e., excavating and retrieving the waste) may optimize the fissile mass density, increase moderation, or create a more favorable geometry for a criticality hazard. Changing one or all of these criticality parameters may increase the likelihood of a criticality accident at the waste retrieval surface.

The nature of the waste configuration limits the controls that can be set. Moderator controls can be implemented during retrieval operations. Moderating material in amounts sufficient to create a near optimally moderated system would be necessary to postulate a critical configuration. Moderator could be introduced into the system during the waste retrieval process by (1) uncovering an intact waste package or intact plastic bag that contains an unsafe amount of free liquid or (2) activation of the deluge fire protection system. In either of these scenarios, introduction of moderating material in an unsafe amount would be required in addition to disturbance of an unsafe amount of fissile material to create a critical configuration. However, even in the presence of an unsafe fissile mass with moderator, creating the near-optimum conditions required to form a critical system will be extremely unlikely.

The plutonium is in an oxide form as PuO_2 . To achieve a critical system with the minimum mass of PuO_2 , the system must be optimally moderated. The closer the system is to the optimum moderation range, the closer it is to the minimum critical mass. A single parameter limit for volume is given in ANSI/ANS-8.1 for systems comprising plutonium nitrate where the Pu-240 is greater than or equal to 5 wt%. This limit is given as 10 L (2.6 gal). This volume takes credit for the nitrate, which is a mild neutron absorber. This value is conservative to use as a volumetric limit even though the expected fissile material form within the retrieval area is PuO_2 . Theoretically, a critical configuration could be formed with a slightly smaller amount of liquid when combined with PuO_2 as opposed to $\text{Pu}[\text{NO}_3]_4$. Using the volumetric limit associated with plutonium nitrate is conservative because of the (1) actual diluteness of the PuO_2 throughout the expected waste matrices, (2) many other mild neutronic absorbers and diluents within the waste constituents that would be mixed with the plutonium, and (3) actual configuration of the PuO_2 in the retrieval area is not in an ordered geometrical configuration. For this analysis, this volumetric limit can be applied as the amount that constitutes an unsafe amount of moderating material (i.e., free liquid) introduced into the system. The systems evaluated in this CSE consist mainly of PuO_2 combined with various matrices, including water. It should be noted that a larger volume of free liquid could be shown to be safe depending on the configuration of the system. For example the minimum critical height for a fully reflected infinite slab of PuNO_3 solution is given as 2.6 in. (ANSI/ANS-8.1), where the Pu-240 is greater than or equal to 5 wt%. Therefore, if the configuration of the solution is a slab no more than 2.6 in. high, an infinite volume would be critically safe. Also, the 10-L (2.6-gal) limit is based on an optimum spherical geometry. Other less-reactive geometries would require larger volumes.

A critical system can be formed with dry oxide material, but the fissile mass necessary to achieve a criticality is quite large. The subcritical limit for PuO_2 systems that contain no more than 1.5 wt% water is given as 11.5 kg of PuO_2 containing 10.2 kg of the fissile isotope Pu-239 (LANL 1996). In dry systems consisting of larger fissile masses (e.g., very near the critical limit), a small amount of moderating material could cause the system to go from safe to an unsafe condition. The expected lower localized fissile masses in the operation indicate that a larger volume of moderating material would be necessary to achieve an unsafe condition. The volumetric limit of 10 L (2.6 gal) also assumes optimum geometry, optimum homogeneous concentration, and full reflection. The first two conditions are idealized and will

not be encountered in this retrieval operation. Additionally, the close-fitting full reflector around the system is also conservative.

6.4.2 Results

Criticality prevention during waste retrieval will use administrative controls that prohibit operations while an unsafe amount of moderator is present. By stopping operations when moderator is present, formation of a criticality hazard will be extremely unlikely.

Scenarios were examined for flooding of the pit and a conclusion reached that additional water would not pose a criticality hazard for existing material in its current form and configuration because of the form and distribution of fissile material and the presence of diluents in current configurations (Sentieri 2003). However, the possibility of moderator being introduced when an unsafe amount of fissile material is disturbed during excavation operations cannot be dismissed. A control can be implemented that prohibits excavation operations in the presence of an unsafe amount of free liquid. If the solution is less than 2.6 in. deep the system will remain safely subcritical. This limitation would prevent the creation of an unfavorable geometrical configuration by creating a more homogenous mixture of possible fissile material present and the unsafe amount of moderating material.

Previous criticality studies have been conducted that determined the effects associated with addition of water in expected configurations and arrays of fissile material. The *Criticality Safety Study of the Subsurface Disposal Area for Operable Unit 7-13/14* (Sentieri 2003) shows the large amounts of fissile mass or the ordered arrangements of fissile mass necessary to postulate a critical configuration.

The excavator bucket was evaluated as a postulated criticality location scenario. This scenario was deemed not credible because of the inherent subcritical nature of the waste, the position of the bucket, and the actual limited time that waste materials are contained in the bucket. When the bucket is in a position to hold water from activation of the deluge system, it is located underneath the boom. Therefore, the introduction of moderating material into the bucket, in sufficient quantity to fully flood the bucket in the presence of an unsafe mass of fissile material, is not probable. Additionally, the control prohibiting the disturbance of waste material in the presence of an unsafe amount of moderator would be applicable and would require that operations cease and the free liquid be absorbed.

Fissile material is not anticipated to accumulate or preferentially concentrate in the waste retrieval area. However, the one area where fissile material may accumulate beyond the expected contamination levels is on the filters of the ventilation system. Fissile material may become airborne and accumulate with other nonfissile dust particles on the filters. The filters will be monitored for radiation fields and pressure differential to ensure material buildup is not occurring. Fissile accumulation on filters is not anticipated to pose a criticality hazard because no mechanism is in place to preferentially concentrate only plutonium particles on the filters.

6.5 Packaging Glovebox System

The PGS design is finalized. Appropriate design provisions or other criticality controls to ensure criticality safety are identified in this CSE.

A mist-type fire suppression system exists in the PGS and the major criticality safety concern would be the introduction of an unsafe amount of moderator in the presence of an unsafe amount of fissile material. The frequency of fires that would necessitate activation of the PGS fire suppression system has been documented in the *Preliminary Documented Safety Analysis for the OU 7-10 Glovebox Excavator Method Project* (INEEL 2002a). This frequency was determined to be an anticipated abnormal event.

In addition, creating an overloaded drum during this retrieval process is not desirable. This is especially true for certain types of waste that would require moderator exclusion while the drums are being repacked. Exclusion of moderator would be necessary for drums containing waste material with higher void-volume fractions and could be postulated to have a reactive configuration of PuO_2 if the drums were to become moderated. These waste types include HEPA-filter media, intact HEPA filters, and unidentifiable combustible material that may include some cellulose material.

The FMM system will be used to estimate the fissile loading of small batches of waste material identified as needing fissile monitoring. The FMM system will consist of the detector assembly, data acquisition system or microprocessor, and the operator control assembly.

Waste material to be monitored will be placed in a 5-gal specimen container. This container then will be placed into the monitoring station. The monitoring station is housed in the glovebox and surrounded on three sides by a 2-in. thick shield. The shielding does not form a watertight seal, thus allowing water to drain out of the monitoring station into the glovebox proper. The detector will be placed outside of the glovebox where it will monitor the fissile material through a window. To create a critical configuration, a minimum of 520 g of Pu-239 must be present in an idealized system. For the cylindrical configuration of the specimen bucket, the critical mass would be greater than 800 g Pu-239. The volume of the specimen container limits the amount of waste that can be placed inside it. It is not credible to get waste in the specimen container with the optimum conditions required for criticality. Additionally, an administrative control exists for excavated waste matrices requiring that fissile monitoring be staged in either the drum-sizing tray, the primary or auxiliary transfer cart for each glovebox, or in a single FMM specimen container for each glovebox. This control eliminates the need to limit the placement of other containers in the PGS. The intent of this staging requirement is to eliminate the accumulation of waste forms needing fissile monitoring in an unapproved location. As these waste forms are moved between approved staging locations, a possibility exists in which a small portion, piece, or fragment of these waste forms could drop onto the floor of the PGS. If operational personnel notice this occurrence, it is expected that the material will be retrieved and placed into an approved staging location. The inadvertent dropping of this material is not a violation of the staging requirement associated with the waste forms requiring fissile monitoring. This logic can be extended to the vacuum in the PGS that will be used for contamination-control purposes to vacuum dust within the gloveboxes. If a small piece of a material needing fissile monitoring were to be inadvertently vacuumed up, it would not be a violation of the intent of the staging requirement, nor would it create an unsafe condition. Waste forms needing fissile monitoring may not be staged in the vacuum; therefore, the vacuum falls into the category of other containers in the PGS that do not require volumetric limits. A volumetric limit exists for the FMM specimen container because waste forms of concern are being staged in that container. This is not the case for the vacuum.

For this evaluation, the PGS will be divided into three operational areas: (1) transfer cart, (2) glovebox, and (3) drum loadout stations. These areas will be evaluated from a criticality safety standpoint.

6.5.1 Transfer Cart

The transfer cart is the method that will be used to transport fissile material into the PGS for evaluation, examination for specific waste matrices, and eventual placement into drums.

The transfer cart is designed as a rectangular tray that is 7 in. deep x 30 in. wide x 42 in. long (see Figure 7). The calculational model evaluated a cart that was 8 in. deep x 50 in. wide x 62 in. long. The cart was evaluated at this size to envelope manufacturing tolerances and also to encompass the dimensions of the drum-sizing tray.

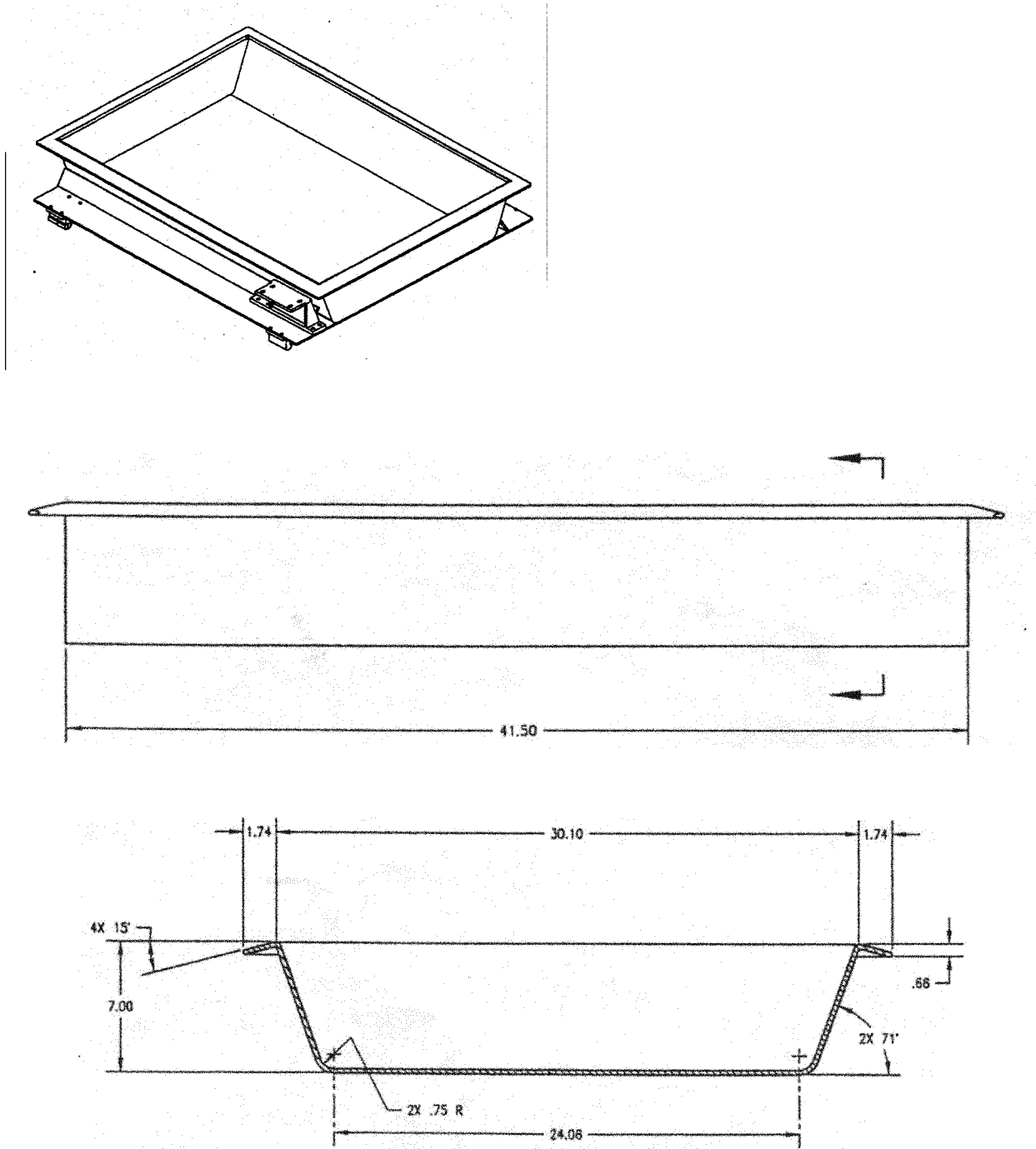


Figure 7. Diagrams of the transfer cart for the OU 7-10 Glovebox Excavator Method Project.

Calculations were performed for various concentrations of PuO_2 distributed in saturated soil. Results of these calculational models (see Table 8) are within the acceptance criterion of $k_{\text{eff}} + 2\sigma \leq 0.95$ (PRD-112). The calculational model evaluated the transfer cart filled with varying solutions of PuO_2 in fully saturated soil with three reflector conditions that are (1) not reflected, (2) fully reflected by water, and (3) fully reflected by saturated soil. In these cases the fissile material was conservatively distributed homogeneously through the entire volume of the transfer cart at the stated concentration.

Table 8. Results from transfer cart calculational models.

Reflector Condition	PuO_2 in Saturated Soil (g/L)	Pu-239 in Transfer Cart (g)	$k_{\text{eff}} + 2\sigma$
Soil	15	5 108	0.869
Water	15	5 108	0.844
None	100	34.052	0.738

As shown by the results in Table 8, a rather large quantity of fissile material is required to achieve an unsafe condition. One of the factors affecting this is the geometry of the transfer cart. The rather shallow design of the cart allows for neutron leakage, which increases the fissile mass necessary to create an unsafe condition. As expected, a large mass of fissile material combined with soil in a homogenous fashion would be necessary to achieve an unsafe condition.

In most cases, a system of fissile material and water would be more reactive, thus requiring a smaller fissile mass to formulate an unsafe condition. A case was modeled consisting of 15 g/L of PuO_2 , combined with water within the volume of the transfer cart. This system was fully reflected on all sides by full-density water. The result of this model yielded a $k_{\text{eff}} + 2\sigma = 0.945$, with 5,108 g of Pu-239 in the system. As shown by this case, a PuO_2 -water system is more reactive than the PuO_2 -soil system; therefore, a lower concentration exceeds the acceptance criterion. However, even for such an idealized system, a large fissile mass is necessary to achieve an unsafe condition in the geometrical configuration of the transfer cart.

6.5.2 Drum-Sizing Tray

The drum-sizing tray has been designed with three sides having an inside height of 17 in. and the fourth side (opposite the end effector attachment) with an inside height of 7 in. (see Figure 5). The design of the drum-sizing tray precludes free liquid from collecting at a height greater than 8 in. if the tray is in a level position. The design of the sizing tray allowed for the height to be reduced on only a single side. Therefore, the allowed 8-in. depth of liquid could be exceeded if the tray were placed on a sloping surface. If the tray were oriented so the side with the reduced height is placed at the top of the slope, liquid would be allowed to accumulate at a depth greater than the allowed 8 in. over a portion of the tray.

Computational models were evaluated within this CSE to determine the effects of the configuration described above. Various gram-per-liter solutions of PuO_2 and water were evaluated. These models showed that a concentration of 11 g/L yielded a $k_{\text{eff}} + 2\sigma = 0.929$, which is less than required for the transfer cart. The concentration necessary to achieve an unsafe condition corresponds to a fissile mass that is not credible (i.e., more than 4 kg of fissile material), as in the case of the transfer cart.

These results show that for a criticality to occur in a transfer cart or sizing tray, a large homogeneously distributed fissile mass must be present along with full flooding. Additionally, the system must be free from neutronic diluents and absorbers in a near optimally moderated configuration surrounded by full reflection. The assumptions used in these models are extremely conservative and the combination of these events is deemed not credible.

6.5.3 Glovebox

Operations in the glovebox involve the following activities:

- Sorting and evaluating material in the transfer cart
- Fissile monitoring those suspect matrices
- Obtaining necessary samples
- Preparing material for placement into the waste drums.

Operations within the glovebox do not exclude the presence of moderating material, but do prohibit operations in the presence of an unsafe amount of free liquid. An unsafe amount of liquid is defined as more than 10 L (2.6 gal) of free liquid in a configuration deeper than 2.6 in. If the solution is less than 2.6 in. deep, then the system will remain safely subcritical.

Criticality controls prohibit performing operations in the presence of an unsafe amount of moderator and monitoring of fissile mass of suspect matrices as the drums are being loaded. An additional assurance for criticality control in the PGS will be the low fissile loading in certain waste matrices (e.g., pieces or remnants of drums) with the need for high fissile masses in these matrices to achieve an unsafe condition.

The possibility exists for the fire suppression system to activate while fissile-bearing waste is present in the PGS; therefore, an administrative control will be put in place to require that operations stop in the presence of an unsafe amount of moderator. If the fire suppression system activates, the free liquid will be absorbed before operations within the PGS are resumed. Fissile monitoring of suspect waste matrices will be completed in the glovebox. The FMM station will consist of a detector placed outside the glovebox. Suspect material will be put in a specimen container and placed in the fissile material monitor for monitoring. These controls will ensure that an unsafe amount of fissile material will not be disturbed in the presence of an unsafe amount of free moderating material.

The geometry of the glovebox does not easily lend itself to the formulation of an unsafe geometry that could lead to an increase in reactivity. The open area of the glovebox floor will disperse material rather than concentrate it. Additionally, the glovebox is designed so some localized shallow pools may form, but it will not hold large quantities of water. The glovebox has an open end that extends into the RCS. This open end does not have a lip; therefore, water will flow back into the retrieval area in the event of the actuation of the fire suppression system.

Liquids in the waste may contain fissile material at undetermined concentrations. The current design of the PGS does not incorporate drip trays or collection receptacles for liquids. Preliminary plans dictate that any free liquids in the transfer cart or the PGS will be absorbed in place if the volume of the liquid is greater than 10 L (2.6 gal) or can be returned to the retrieval area provided the total volume is less than 10 L (2.6 gal).

The specimen container used in conjunction with the FMM will be designed so its volume does not exceed 20.8 L (5.5 gal). The volume of the specimen container limits the amount of waste that can be placed inside it. It is not credible to get waste in the specimen container with the optimum conditions required for criticality.

6.5.4 Drum Waste Loading and Drum Loadout Stations

The final step in the process is to place the waste material that has been retrieved from the waste retrieval area, sorted and monitored, if needed, into waste drums for disposition (see Figure 8).

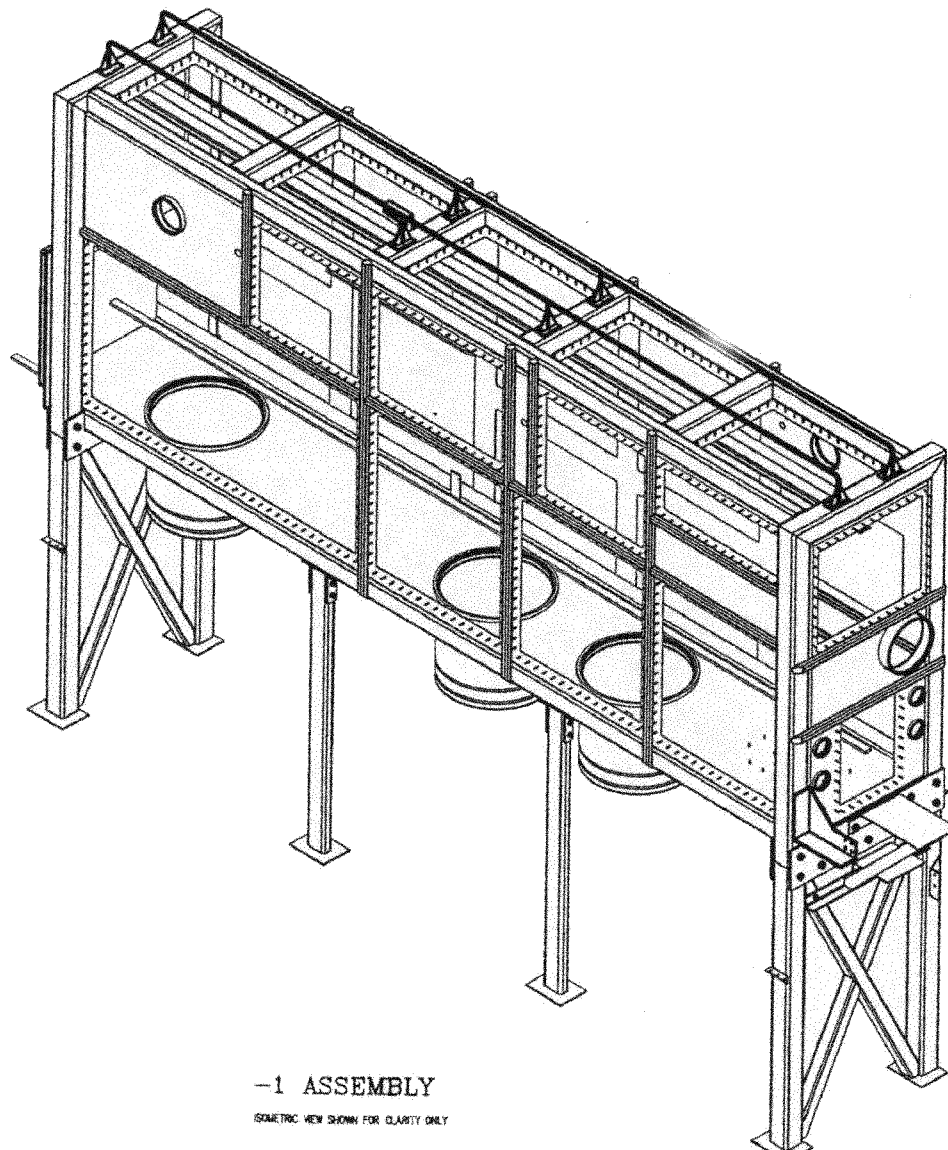


Figure 8. Isometric of glovebox and drum loadout for the OU 7-10 Glovebox Excavator Method Project.

The most probable location to postulate a critical configuration is within the confines of a 55-gal drum. If certain types of material (e.g., filter media containing fissile material) were placed in a 55-gal drum without being monitored, the drum could be flooded and a critical configuration could be

postulated. Some waste forms (e.g., HEPA filter media) tend to form a more homogenous distribution of fissile material within a matrix that can have a wide range of void volume fractions. Computational models were evaluated (Sentieri 2003) consisting of PuO_2 dispersed within intact HEPA filters. These models confirm the reactive nature of this waste form with respect to criticality safety.

Monitoring and ensuring adherence to the drum fissile-loading limit of 380 g FGE per drum will provide a control for ensuring that a critical configuration does not form. Operational drum-loading limits will be set at 200 g FGE per drum. This is the current fissile-loading limit delineated in the *Idaho National Engineering and Environmental Laboratory Waste Acceptance Criteria* (DOE-ID 2002). Drums meeting the 200 g FGE limit can be stored at the RWMC in accordance with the current RWMC drum storage requirements. The criticality administrative control limit is set at 380 g FGE per drum. Analysis shows that an array of up to 500 drums in a 10 x 10 x 5-high configuration is critically safe (see footnote c). The estimated number of drums produced from this retrieval effort will be approximately 500.

Other waste forms require very large fissile masses to postulate the formation of a critical system. Matrices that comprise sludge material, soil, and some visually identifiable combustibles are expected to contain waste material combined with low fissile-gram quantities (e.g., PPE). The low level of fissile loading per drum resulted from processes that produced these waste matrices. Historical assay data confirm low fissile loading in drums containing these materials. In addition, because of the nature of this waste, fissile material contained in these types of matrices would have to exist in homogeneous multiple-kilogram quantities before they would become a criticality safety concern, which is not credible. Therefore, matrices that have been determined to have low fissile loading because of their process origination (i.e., comprising sludge material, soil, and visually identifiable combustibles) will be loaded directly into waste drums without any fissile monitoring.

Whether or not waste forms need to be monitored can be approached by one of two methods:

- **Method 1:** The first method would be to dismiss the need for monitoring based on a qualitative argument, which would qualitatively dismiss the formation of a critical system based on historical process knowledge, the nature of the constituents comprising the waste form, or the form of the waste itself. The use of historical process knowledge can be used to dismiss the need to assay certain forms of waste before loading into a drum. Personal protective equipment will have very low fissile loading; therefore, this waste form does not need to be monitored before being placed into a drum. Additionally, plutonium is not homogeneously dispersed in plastics used for contamination control purposes; therefore, these plastics do not need to be fissile monitored before being placed in a waste drum.

Using the constituents present in the waste form, as a basis for not monitoring the waste form, before placement into a waste drum is another valid approach. A good example of this would be the Series 745 sludge with constituents containing a large amount of chlorine in the form of various salts. Chlorine is a good neutronic absorber and increases the fissile mass necessary to achieve an unsafe condition.

An example of using the waste form itself as a reason for not monitoring the waste before loading in a drum would be drum remnants. These drum remnants would contain surface contamination of plutonium; therefore, very small plutonium masses would be expected in this waste form. Drum remnants from the dig area do not need to be monitored before loading.

- **Method 2:** The second method to dismiss the need for fissile monitoring a waste form is quantitatively by creating computational models of the specific waste forms to show fissile masses necessary to achieve an unsafe condition. Because the majority of waste expected in the dig area

comprises sludge, soil, and some graphite, these three waste forms were evaluated using computational models to determine the levels at which unsafe conditions would occur. Expected waste matrices from process burial history are analyzed in the following sections.

6.5.5 Waste Materials

6.5.5.1 Waste Matrices Not Needing Fissile Monitoring. The forms and compositions of some of the waste matrices do not require fissile monitoring before placement into a waste drum. These matrices are discussed in the following subsections.

6.5.5.1.1 Sludge — The Series 74 sludge consist of first stage sludge (Series 741), second stage sludge (Series 742), organics (Series 743), special setups (Series 744), and salts (Series 745). A more complete description of these sludge forms can be found in *Acceptable Knowledge Document for INEEL Stored Transuranic Waste-RFP Waste* (WASTREN 1998). Historically, the fissile loading in the Series 741, 742, and 743 sludge and Series 745 salt matrices is very low. The Series 744 sludge matrix has a slightly higher fissile loading than the other four listed matrices. Of the 1,650 drums of Series 744 sludge currently in aboveground storage, 76 have been assayed with only four sludge drums determined to contain higher than the 200 g fissile-loading limit. All four of these drums have less than 380 g FGE with assays of 219.9, 251.6, 307.5, and 350.2 respectively.

Series 741 sludge consists of immobilized materials generated from the first stage treatment operations in RFP Building 774. Aqueous liquids coming into the process originated from RFP Building 771 recovery operations. The aqueous waste was made basic with the addition of NaOH to precipitate out waste constituents including a small amount of plutonium oxides. This precipitate was filtered to create a sludge that was eventually mixed with Portland cement (WASTREN 1998). Approximately two waste drums of sludge were created from a tank of waste solution.

The first stage aqueous liquid waste was held in Raschig-ring filled transfer tanks in RFP Building 771 before transfer to RFP Building 774. Analytical samples were taken before transfer of the aqueous liquid waste from RFP Building 771 to Building 774 because the transfer was made into large critically unsafe geometry tanks in RFP Building 774. The unsafe geometry tanks in RFP Building 774 were limited to a total fissile mass loading of 200 g. Therefore, the amounts and transfers of fissile material to these tanks were tracked before shipment to ensure compliance with the 200-g fissile limit.

Series 742 sludge consisted of immobilized materials generated from the second-stage treatment operations in RFP Building 774. The Series 742 sludge underwent a similar process described for the Series 741 sludge. Historically these sludge matrices contained small amounts of plutonium. Therefore, these waste forms will not need to be assayed before being placed in a drum because this waste form is not likely to overload a waste drum with more than 200 g FGE. If this loading was exceeded, it is not credible to load a drum with enough fissile material in this matrix to form an unsafe condition.

To bolster confidence in this approach, a set of computational models was developed to determine the fissile mass necessary to create an unsafe condition within these matrices. Both the Series 741 and 742 sludge matrices have a large amount of moisture; therefore, relatively substantial hydrogen content exists. Two approaches were developed. The first approach evaluated Series 741 sludge containing various concentrations of Pu-239 in the form of PuO₂ distributed homogeneously throughout an entire single waste drum fully loaded with Series 741 sludge. Composition of the sludge (Schuman and Tallman 1981) used is given in Appendix C. The model assumed full reflection around the entire drum with saturated soil, which is slightly more conservative than water reflection (see Table 8). Results of these cases are given in Table 9.

Table 9. Results from PuO₂ in Series 741 sludge within each waste drum.

PuO ₂ in Series 741 Sludge (g/L)	Pu-239 per Drum (g)	H/Pu Ratio of System	k _{eff} + 20
5	914.1	3,306	0.485
10	1,828.2	1,653	0.648
15	2,742.3	827	0.884

As shown by results given in Table 9, the system will remain subcritical even with a fissile loading of 2.7 kg of Pu-239 mass in a single drum. The fissile material was distributed through the drum in a homogeneous manner. Another model was evaluated in which PuO₂ was distributed in a system of Series 741 sludge in the form of a sphere. For this model, 1,500 g of Pu-239, in the form of PuO₂, was distributed within the sludge material over increasing volumes within a sphere. The radius of the fissile material and sludge was increased to determine optimum conditions. The previous set of cases evaluated fissile concentration over a set volume. This model evaluates varying concentrations for a given fissile mass. The sphere of plutonium and sludge was fully reflected by saturated soil. Results from these cases are given in Table 10.

Table 10. Results from PuO₂ in Series 741 sludge in spherical form at optimum moderation.

Radius of PuO ₂ and Series 741 sludge (cm)	Mass of Pu-239 Contained in Sphere (g)	H/Pu Ratio of System	k _{eff} + 20
10	1,500	40.7	0.609
15	1,500	137.5	0.794
20	1,500	325.9	0.889
25	1,500	636.4	0.890
30	1,500	1,099.7	0.821
35	1,500	1,746.3	0.716

As shown by the results in Table 10, a model containing 1,500 g of Pu-239 is subcritical in an optimum geometry at optimum moderation within the specific matrix and full reflection around the system. These results show that it is not credible that a criticality event associated with the Series 741 sludge matrix could occur for the expected fissile masses.

Composition of the Series 742 sludge is given in Appendix C, which shows it is very similar to Series 741 sludge (Schuman and Tallman 1981). The same arguments applied to justify not assaying the Series 741 sludge can be used to justify not assaying the Series 742 sludge before loading the waste in this matrix into a drum.

The Series 743 sludge waste matrix consisted of various types of organic liquid waste transferred to RFP Building 774 to be mixed with a synthetic calcium silicate to form a paste or grease-like substance. These organic waste liquids were primarily composed of oil and chlorinated solvents used in degreasing and machining operations in RFP Buildings 707 and 777. The composition of the mixture consisted of

approximately 114 L (30 gal) of liquid organic waste to 45 kg of Micro-Cel E (i.e., synthetic calcium silicate).

Computational models were developed to determine the fissile mass necessary to create an unsafe condition within these matrices. The same methods used for the Series 741 sludge were used for the Series 743 sludge. The first models developed consisted of PuO_2 at various concentrations distributed homogeneously through an entire single waste drum of Series 743 sludge that was fully reflected on all sides with saturated soil.

The second set of models evaluated 1,500 g of Pu-239, in the form of the PuO_2 combined with Series 743 sludge in spherical form to determine most reactive concentrations. The composition of Series 743 sludge consisted of approximately 114 L (30 gal) of oil (80%) and CCl_4 (20%) combined with approximately 45 kg of Micro-Cel E, a synthetic calcium silicate. The formulation for the Series 743 sludge, as it was modeled, can be found in the associated spreadsheets contained in Appendix B. Spherical models also were evaluated as fully reflected by saturated soil.

As shown by the results given in Table 11, the system will remain subcritical with a fissile loading of 3.6 kg of Pu-239 mass in a single drum.

Table 11. Results from PuO_2 in Series 743 organic setup sludge within each waste drum.

PuO_2 in Series 743 Sludge (g/L)	Mass of Pu-239 Contained in Drum (g)	H/Pu Ratio of System	$k_{\text{eff}} + 20$
5	914.1	5,018.5	0.147
10	1,828.2	2,509.3	0.270
15	2,742.3	1,672.8	0.373
20	3,656.4	1,254.6	0.460

As shown by the results in Table 12, a model containing 1,500 g of Pu-239 in an optimum geometry, at optimum moderation within the specific matrix, and full reflection around the system remains safely subcritical.

Table 12. Results from PuO_2 in Series 743 organic setup sludge in spherical form at optimum moderation.

Radius of PuO_2 and Series 743 sludge (cm)	Mass of Pu-239 Contained in Sphere (g)	H/Pu Ratio of System	$k_{\text{eff}} + 20$
10	1,500	61.8	0.644
15	1,500	208.6	0.707
20	1,500	494.5	0.638
25	1,500	965.8	0.490
30	1,500	1,668.9	0.366
35	1,500	2,650.3	0.261

These results show it is not credible that a criticality event could occur, associated with the Series 743 sludge matrix, for the expected fissile masses.

Series 744 sludge consisted of special setups from operations that did not have a direct feed into the waste processing buildings or the waste produced from special operations that were not chemically compatible (WASTREN 1998) with the waste process stream in RFP Building 774. The liquids included mostly complexing agents, strong acids, and strong bases. The liquids were transferred in polyethylene bottles to a glovebox. The liquid then was transferred to a *tank* where acid waste was neutralized. Basic solution was left untreated. A mixture of approximately 93 to 112 kg of Portland cement and 37 to 56 kg of insulation cement was combined with 80 to 100 L (21 to 26 gal) of the basic waste or neutralized liquid in a 55-gal drum. The drum then was placed onto a drum roller for mixing.

The combination of the 80 to 100 L (21 to 26 gal) of Series 744 waste solution with the cements would yield compositions similar to those modeled for the Series 741 and 743 sludge. Therefore, similar fissile masses would be safe for the Series 744 sludge composition as those shown safe for the Series 741 and 743 sludge. Therefore, the Series 744 sludge does not need to be fissile monitored before placement into a drum.

Series 745 sludge consisted of evaporator salts. The low fissile mass, low hydrogen content because of the low moisture content, and chemical composition of this sludge type, indicate this sludge matrix will be less reactive than those previously evaluated. No criticality concerns associated with this sludge form have been identified and this waste does not need to be fissile monitored before placement into a waste drum.

After the sludge type waste has been loaded into a drum, the drum will be placed into lag storage until it can be assayed to ensure compliance with the fissile drum-loading limits.

6.5.5.1.2 Soil — Anderson (EDF-2158) estimates that over 50% of the waste zone within the waste retrieval area is composed of soil. As the drums within the waste zone deteriorated, the waste material, along with its fissile components, became intermixed with the surrounding soil. Additionally, in the process of recovering the waste material, the excavator will tend to mix waste material with the soil. To expedite the waste retrieval and repackaging process, the soil recovered will be placed directly into a waste drum without being fissile assayed while loading. After the waste has been loaded into a drum, the drum will be placed into lag storage until it can be assayed to ensure compliance with the fissile drum-loading limits.

Each excavator load will be placed onto a lined transfer cart and brought into the PGS. Operational personnel then will sort through the cart to remove those items identified for fissile monitoring because of the potential higher fissile loading associated with these certain matrices. Other waste forms that have been identified to not need fissile monitoring will be loaded directly into a waste drum. The remaining soil contained in the liner will be transferred directly into a waste drum. Once a waste drum is full, it will be decontaminated, brought out of the drum-out tent, placed into lag storage, and eventually assayed for fissile content.

To address this issue, computational models were developed to determine the fissile mass necessary to create an unsafe condition within a soil matrix. The same approach used in the sludge models was used for the soil models. The first approach evaluated soil containing various concentrations of Pu-239 in the form of PuO₂ distributed homogeneously through a fully loaded soil waste drum. The composition of the soil (Callow et al. 1991) used is given in Appendix C (see Tables C-1 through C-3). The soil was modeled with the 40% volume fraction within the soil filled with water, which is fully

saturated soil and is very conservative. The model assumed full reflection around the entire drum with saturated soil. Results of these cases are given in Table 13.

Table 13. Results from PuO₂ in soil within each waste drum.

PuO ₂ in Soil (g/L)	Mass of Pu-239 Contained in Drum (g)	H/Pu Ratio of System	k _{eff} + 20
5	914.1	2534	0.599
10	1828.2	1267	0.851
13	2376.7	974	0.941
15	2742.3	845	0.987

As shown by the results given in Table 13, the system will remain subcritical with a fissile loading of 2.3 kg of Pu-239 mass in a single drum. This model assumed the fissile material was distributed through the drum in a homogeneous manner.

Another model was evaluated in which the PuO₂ was distributed in a system of soil in the form of a sphere. For this model, 1,500 g of Pu-239, in the form of PuO₂, was distributed within the saturated soil material over increasing volumes within the sphere. The radius of fissile material and soil was increased to determine the point of optimum moderation. The previous set of cases evaluated fissile concentration over a set volume. This model evaluates varying concentration for a given fissile mass. The sphere of plutonium and saturated soil mixture was fully reflected by saturated soil. Results from these cases are given in Table 14.

As shown by the results in Table 14, the system is subcritical with a model containing 1,500 g of Pu-239 in an optimum geometry, at optimum moderation within the specific matrix, and full reflection around the system. These results show it is not credible that a criticality event could occur within the soil matrix for the expected fissile masses. The composition of the soil is given in Appendix C. It cannot be ruled out as impossible that a drum of unassayed soil will exceed the drum fissile loading limit of 380 g FGE. However, these calculations show that fissile mass necessary to achieve an unsafe condition is very large in comparison to the expected fissile mass within the waste retrieval area and would require homogeneous distribution of the fissile material and full flooding.

Table 14. Results from PuO₂ in soil in spherical form at optimum moderation.

Radius of PuO ₂ and Soil (cm)	Mass of Pu-239 Contained in Sphere (g)	H/Pu Ratio of System	k _{eff} + 20
10	1,500	31.2	0.566
15	1,500	105.3	0.753
20	1,500	249.6	0.883
25	1,500	487.7	0.934
30	1,500	842.7	0.910
35	1,500	1,338.2	0.840

6.5.5.7.3 Other Waste Materials Not Needing Fissile Monitoring Before Drum Loading—Other waste forms that do not need to be fissile monitored before being placed into waste drums are discussed below:

- **Drum remnants:** Drum remnants do not need fissile monitoring before being loaded into a waste drum. The expected fissile material associated with this waste form will exist as surface contamination. Therefore, these waste forms should not contribute much fissile mass to the total drum inventory.
- **Personal protective equipment:** Waste matrices that can be identified as PPE do not need to be fissile monitored before being loaded into a waste drum. The expected fissile mass associated with this waste form should be at or slightly above contamination levels. Aboveground assaying of this waste form has yielded no drums in excess of the 200 g fissile drum-loading limit.
- **Plastic materials used in contamination control:** Waste matrices that can be identified as plastic sheets used for contamination control purposes do not need to be fissile monitored. This matrix should have only surface contamination and not contain high fissile material concentrations.

All drums will be placed into lag storage until the drums can be assayed for fissile content. The lag storage area will allow 500 drums stored in a five-high array with no spacing requirements.

6.5.5.2 Waste Matrices That Need Fissile Monitoring. The following subsections discuss those matrices identified as needing fissile monitoring before being placed into a waste drum. The fissile loading associated with the monitored amount will be tracked and added to the amount of total fissile inventory in the drum. This will help to ensure that the single drum fissile-loading limit of 380 g FGE is met.

6.5.5.2.1 Graphit — Discussions with past RFP operational personnel indicate that the graphite waste matrix could contain a higher fissile loading than most of the other waste forms. Graphite was used as a mold material into which various parts were cast. Approximately 50% of the aboveground stored waste drums of this item description code (IDC) have been fissile assayed. This fissile assaying has determined that three of these drums contain more than 200 g but less than 380 g FGE per drum.

Some of the RFP graphite molds were used to form classified shapes. Plutonium recovery operations for these classified molds involved crushing the molds completely followed by a leaching process to recover the plutonium. Once the molds were crushed into small particles the plutonium leaching recovery process was quite efficient.

Other RFP graphite molds involved the creation of plutonium ingots. These ingots were turned into parts by various operational processes. For the most part, these types of graphite molds were not classified. A surface scarifying process was employed to recover as much plutonium as possible from these types of molds. Once the plutonium was scarified from an unclassified mold, it was reused if possible or placed into a drum for eventual disposal at the INEEL.

In some instances, the scarifying process caused the molds to break apart, thus rendering them unusable. These chunks were disposed of as waste. In some cases the molds themselves had surface defects allowing molten plutonium to penetrate fissures and cracks within the mold. In these cases, the scarifying process would not be able to recover these small plutonium deposits within the mold fissures. Therefore, the molds were a reasonable candidate for higher plutonium holdup. Because of the potential for holdup of plutonium, graphite found in the waste retrieval area should be fissile monitored before being placed into waste drums.

Types of graphite that should be fissile monitored include intact molds, an intact bag full of intact molds or large pieces of molds, or a large cache of larger graphite pieces dumped into the transfer cart from the waste retrieval area. Small pieces of graphite (measuring less than approximately 2 in. in diameter), if found intermixed in the soil, do not need to be fissile monitored as long as they are not part of a large grouping of graphite that has been brought into the PGS. Implementation of these criteria will be defined more thoroughly as the operational procedures are finalized. The intent is to fissile monitor the larger pieces that may contain plutonium hold up rather than going through the waste to ensure every single miniscule piece of graphite has been fissile assayed.

Probe-hole data indicate that one localized area in the retrieval area (designated as P-920) could contain up to as much as 2,217 g of plutonium. This value represents the worst-case condition and is very conservative and was determined to be extremely unlikely (SAR-4 Addendum J 2003). A value of 547 g was determined to be unlikely (SAR-4 Addendum J 2003) from the P-920 data. Records indicate that the area reportedly contains graphite waste. Calculational models evaluated in a previous study (Sentieri 2003) demonstrate that a large fissile mass is necessary to achieve an unsafe condition in a graphite waste system. It was shown in the previous study (Sentieri 2003) that a spherical system of 1,000 g of weapons grade plutonium, in the form of plutonium oxide combined with water and graphite, would remain safely subcritical. Assuming a system containing 1,000 g of plutonium is very conservative and encompasses the estimated unlikely fissile amount from the P-920 data. The amount of water present corresponds to the void volume fraction of the system. This volume fraction was modeled from 10 to 40% with 40% being the most conservative. This value was chosen as the limit for the volume fraction because volume fractions beyond this level begin to encroach on solution systems. Such systems are not credible for the waste forms and chemical compositions expected. The system was fully reflected with fully saturated soil thus decreasing neutron leakage. These calculational models are extremely conservative yet still yield subcritical systems. Introduction of the data relating to Probe P-920 does not invalidate the control scheme being implemented in the PGS. It is extremely unlikely that such a large fissile mass is present in the area. However, if such a mass were present, then it would need to be fully moderated and distributed in near idealized conditions to achieve an unsafe condition.

Though these calculational models demonstrate subcriticality for rather large fissile masses, suspect matrices that could contain higher fissile loading should be fissile monitored before being placed in a waste drum to prevent the creation of an overloaded drum (i.e., FGE equal to or higher than 380 g per drum).

6.5.5.2.2 Intact High-Efficiency Particulate Air (HEPA) Filters, HEPA Filter Media, and Material Not Distinguishable from HEPA Filter Media—An IDC of 376 is associated with each of these drums. This IDC is identified as filter media. Historical RFP process knowledge leads to the conclusion that this IDC could have a higher fissile loading (i.e., higher than of 200 g per drum). Historical data indicate that no filter media is expected in the waste retrieval area. However, historical burial records cannot be relied on with total confidence.

The physical nature of filter media and intact filters lends itself to more optimal conditions, unless the filter media or intact filter is compressed or degraded, with regard to creating a critical configuration. This waste form consists of material with a low physical density, a high void volume fraction, a more homogenous distribution of fissile material, and a history of high fissile assaying. The combination of these factors increases the probability for the formation of a postulated critical configuration in a fully moderated situation. Moderator control (not exclusion) will be implemented in this operation. Disturbance of waste material in the presence of an unsafe amount of free liquid will be prohibited until the free liquid is absorbed. An unsafe amount of liquid is defined as more than 10 L (2.6 gal) of free liquid in a configuration deeper than 2.6 in. If the solution is less than 2.6 in. deep, then the system will remain safely subcritical. Therefore, intact HEPA filters, HEPA filter media, and waste materials that cannot be

distinguished from HEPA filter media, will be fissile monitored in the glovebox FMM system before being placed in a waste drum.

6.5.5.2.3 Containerized Unknown Waste Materials with Potential of Having Unsafe Plutonium Masses — Retrieved unidentified containerized waste forms with potential for having unsafe masses of plutonium will need to be fissile monitored before being placed in a waste drum. The evaluation considered various sources that could be associated with unsafe quantities of fissile masses. Containerized unknowns need to be grouped into the category of items having the potential to introduce an unsafe mass into a waste drum. In the presence of sufficient moderating material, this unsafe mass creates a postulated scenario. Therefore, containerized unknowns will need to be fissile monitored to determine whether fissile material is present.

6.6 Drum Lag Storage

6.6.1 Drum Lag Storage Area

Drums that contain waste matrices comprising sludge, soil, and certain identifiable combustible material (e.g., PPE) will be loaded directly into drums without the fissile content being monitored in the PGS. This is because these waste forms basically preclude criticality for credible fissile masses because of their composition and constituents or (from historical process knowledge) do not contain appreciable amounts of fissile material, but rather contamination levels. Waste forms that do not require monitoring before placement in a waste drum are not expected to have fissile loading that exceeds the 380 g FGE limit per drum. Other waste forms of concern will be monitored for fissile content before placement in a drum. This will ensure that the loaded waste drum meets the fissile loading requirement. Therefore, the unassayed waste drums can be stored in a five-high array as long as no more than 500 drums comprise the array (see footnote c).

If, after assaying, the fissile material loading requirements are not met (more than 380 g FGE in a drum), then the waste storage containers will be overpacked to prevent water intrusion and then sent to a spaced storage array in an overloaded- or isolation-drum criticality control area. The spacing requirements in the overloaded-drum criticality control area are a single planar array of drums maintained at a 16-in. edge-to-edge spacing if fissile-gram loading is greater than 380 g FGE and less than or equal to 1,500 g FGE. The spacing requirements in the isolation-drum criticality control area are a single planar array of drums maintained at 6-ft edge-to-edge spacing if fissile-gram loading is greater than 1,500 g FGE.^f

Drums assayed and confirmed to meet the INEEL waste acceptance criteria will remain safely subcritical in any configuration. The drums in the lag storage area will contain waste materials that have not been assayed using whole-drum counting techniques. Assaying of the drums is not required before placement of the drums into lag storage.

Additionally, HEPA and roughing filters used in the PGS and RCS ventilation systems need to be treated and disposed as any other secondary waste materials associated with the project. These filters may become contaminated with plutonium, but not to the extent of being a criticality concern. The fissile mass can be estimated from process knowledge or quantified by assaying techniques before disposal.

f. Woods, K. B., and M. N. Neeley, 2001, *Criticality Safety Evaluation for Overloaded Drums at the Radioactive Waste Management Complex*, INEL/INT-97-00695, Rev. 1, INEEL.

Secondary waste is a generic category for waste streams that result from support activities associated with the retrieval and packaging of waste zone, OU 7-10 materials.

6.7 Samples

The current field sampling plan calls for the collection of soil and sludge materials to accomplish confirmatory analyses relating to applicable characterization requirements (Salomon et al. 2003). Samples taken from the waste zone will be fissile monitored before transportation to analytical laboratory facilities to determine the fissile content. The purpose is to ensure compliance with applicable transportation requirement, which limit a package to no more than 15 g of fissile material. Samples from the waste zone will be collected in nominal 250-mL containers. The types of waste matrices being sampled (e.g., soil and sludge), along with the expected amounts of fissile material in the samples, and the fact that all samples are being fissile monitored before storage and transportation, lead to the conclusion that no credible criticality scenarios exist relating to these samples.

After the waste has been removed from above the underburden, the project plans to take several core samples of soil. These samples will be contained in nominal 2-in. diameter cores between 24 and 54 in. long. Each sample will be shipped individually in an approved shipping package and transferred to INTEC. Fissile material in the underburden will only occur as a contaminant and there are no known pathways for significant quantities of plutonium to migrate to and concentrate in the underburden. Even if plutonium did get to the underburden, Section 6.5.5.1.2 determined that there is no credible criticality scenario with a drum of soil containing well over a kilogram of plutonium. There is no need to require fissile monitoring or assaying of the underburden core soil samples for criticality safety. Fissile monitoring and assaying is only required for samples from the waste zone.

6.8 Deactivation, Decontamination, and Decommissioning

The “Facility Shutdown Plan and Deactivation, Decontamination, and Decommissioning Pre-Plan for the OU 7-10 Glovebox Excavator Method Project” (PLN-343) outlines the steps for deactivation, decontamination, and decommissioning of the project facility. The Facility Shutdown and Layup Plan (PLN-1455)^g supercedes PLN-343 to specifically address the shutdown and layup phases of the project. This plan outlines the steps to reduce and immobilize contamination, stabilize the excavated portion of the pit, and place the facility into a safe and cost-efficient condition for the layup phase of the project.

Included in the shutdown steps are housekeeping of the PGS and RCS, grouting of the retrieval area, and encapsulating residual surface contamination in the RCS and PGS by fogging the confinement with a glycerin and water solution. Housekeeping in the PGS entails disposing of hand tools and unused materials as well as vacuuming and disposing of residual (spilled) waste in the gloveboxes. Housekeeping in the RCS entails the following:

- Cleaning excavator tools
- Saturating spilled soils with the glycerin and water solution for contamination control purposes and returning soils to the excavation

g. PLN-1455, “Facility Shutdown and Layup Plan for the OU 7-10 Glovebox Excavator Method Project (Draft),” Rev. OA, WEEL, November 2003.

- Returning waste forms (i.e., suspect fissile material) to the excavation that would require fissile monitoring before placement in a drum.

Waste forms not requiring fissile monitoring may be vacuumed following this effort. The housekeeping is intended to remove waste forms needing fissile monitoring that can be readily observed. It should be noted that small fragments of these waste forms may be interspersed in the remaining soil or dust in the RCS and PGS, and such remnants pose no criticality hazards.

Staging requirements exist to eliminate accumulation of waste forms needing fissile monitoring in an unapproved location. This eliminates the need to control geometry and volume of containers and equipment in the RCS and PGS. As waste is removed during excavation and placed into the transfer cart, waste forms needing fissile monitoring could drop onto the floor of the RCS. The vacuum in the RCS and PGS will be used for contamination control purposes to vacuum up dust and waste matrices not requiring fissile monitoring. If a small piece of a material needing fissile monitoring were to be inadvertently vacuumed up, it would not be a violation of the intent of the staging requirement, nor would it create an unsafe condition. Waste forms needing fissile monitoring may not be staged in a vacuum; therefore, the vacuum falls into the category of other containers in the PGS and RCS that do not require geometry and volumetric limits.

The use of a liquid glycerin agent for fogging does not pose a criticality concern because of the low amount of fissile material and the form and distribution that will be associated with the residual waste remaining in the RCS and PGS. The fog-dispersion method produces a thin film of liquid over the entire confinement. Before grouting of the excavation, the requirement is applicable that prohibits disturbance of waste in the presence of more than 10 L (2.6 gal) of free liquid that is deeper than 2.6 in.

No criticality concerns exist with the placement of grout into the open excavation area. Pouring grout into the excavation area will result in grout contacting waste in exposed areas, but this contact will not create an unsafe condition. Although the grout contains moderator, it also contains diluents or absorbers, and there is no mechanism or sufficient fissile mass to create an unsafe condition. The nature of the grout, both its physical properties and chemical composition, preclude the formation of an unsafe system. The grout that has been chosen to fill the excavation is self-leveling, thus eliminating the need to mechanically level the grout as it is poured into the excavation. The commingling of exposed waste matrices in the waste seam and the grout pose no criticality hazards.

No criticality concern exists after the housekeeping and grouting activities are complete because of the low amount of fissile material associated with surface contamination that will remain in the facility.

7. DESIGN FEATURES AND ADMINISTRATIVELY CONTROLLED LIMITS AND REQUIREMENTS

The following engineering and administrative controls have been identified in this CSE. These controls are required to ensure criticality safety during Stage II operations.

7.1 Engineering Controls

The engineering controls associated with criticality for the OU 7-10 Glovebox Excavator Method Project are listed below:

- **Transfer cart dimensions:** The height of the transfer cart was evaluated up to 8 in. and therefore is a dimension of importance to criticality safety. The transfer cart is designed to be less than 8 in. high with an inside length and width not exceeding 50 by 62 in.
- **Drum-sizing tray features:** The drum-sizing tray will be designed with the side opposite the end effector lifting attachment having an inside height no more than 8 in. and the inside height of each of the remaining sides not more than 18 in. The inside length and width will be designed not to exceed 50 by 62 in.
- **Volume of the fissile monitor specimen container:** The volume of the FMM specimen container will be limited to no more than 20.8 L (5.5 gal). This control is safety significant.
- **Criticality alarm system:** The presence of a criticality alarm system and locations of the detector clusters is an engineered safety feature (Norman 2002).

7.2 Administrative Controls

This CSE provides administrative controls for the safe removal, handling, and storage of fissile material. These controls ensure favorable geometry and mass controls that will reduce the likelihood for a criticality accident. The administrative controls for the project are discussed below:

7.2.1 Fissile Material Loading Limit

Drums shall be loaded to no more than 380 g Pu-239 FGE. The actual drum loading will be limited operationally to 200 g Pu-239 FGE. Additionally, excavated waste matrices requiring fissile monitoring will be staged in either the drum-sizing tray, the primary or auxiliary transfer cart for each glovebox, or in a single FMM specimen container for each glovebox. This requirement eliminates the need to control the placement of other containers into the PGS. Staging refers to the initial placement of the material into the transfer cart, auxiliary cart, or placement into the FMM specimen container for sorting and assaying.

Waste matrices not needing fissile monitoring before placement in a drum include sludge, soil, visibly identifiable combustibles (e.g., PPE and plastics) that were used for contamination control purposes, and drum remnants.

Waste matrices needing fissile monitoring before placement in a drum are waste materials of concern (e.g., filter media, material not distinguishable from intact filters, intact graphite molds, pieces of graphite molds bigger than approximately 2 in. in diameter, and other containerized unknowns that could potentially contain unsafe quantities of fissile material) that must be fissile monitored as drums are being loaded to ensure compliance with the drum fissile-loading limits of 200 g FGE per drum and not exceeding the criticality administrative control limit of 380 g FGE per drum.

7.2.2 Operations in the Presence of Free Liquid

If an unsafe amount of liquid (i.e., more than 10 L [2.6 gal] of free liquid in a configuration deeper than 2.6 in.) is encountered in the RCS or PGS during retrieval or packaging operations, then all disturbance of fissile material in the area of the discovery will be prohibited. If the solution is less than 2.6 in. deep, then the system will remain safely subcritical. Operations within the area of discovery may resume after the free liquids have been absorbed to less than the administrative controls.

7.2.3 Criticality Alarm System

A Criticality Alarm System is required and provides coverage over the waste retrieval area and the PGS during retrieval and packaging operations in accordance with the “Criticality Safety Program Requirements Manual” (PRD-112) and ANSI/ANS-8.3, “Criticality Accident Alarm System” (ANSI 997).

7.2.4 Drums in Lag Storage

Drums that have not been fissile assayed, this includes drums containing materials that have been monitored in the FMM, may be stored in a five-high array provided the total number of drums in the array does not exceed 500 (see footnote c). Drums that have been assayed and shown to contain more than 380 g FGE shall be stored in accordance with the requirements in the criticality safety evaluation relating to overloaded drums (Woods and Neeley 2001).

7.2.5 Sampling Activities

Samples taken from the waste zone will be fissile monitored to determine fissile content. Fissile monitoring of the underburden core samples is not required for criticality safety.

8. SUMMARY AND CONCLUSIONS

The criticality potential of the OU 7-10 Glovebox Excavator Method Project and the necessary associated controls have been analyzed in this CSE. The criticality potential in the waste retrieval area, the PGS, and the drum lag storage area were evaluated. The probability of criticality has been deemed extremely unlikely because of the expected forms of waste in which the fissile materials are distributed. In addition, achieving a critical system is physically impossible without the presence of sufficient moderator. Controls will be implemented to prohibit operations in the presence of an unsafe amount of free liquid. An unsafe amount of liquid is defined as more than 10 L (2.6 gal) of free liquid in a configuration deeper than 2.6 in. If the solution is less than 2.6 in. deep the system will remain safely subcritical.

Waste will be categorized into two groups: (1) waste that does not require fissile monitoring before placement in a drum and (2) waste that does require fissile monitoring before being placed in a drum. This is based on the form and distribution of fissile material in the waste along with the historical inventory data associated with the expected waste matrices contained in the dig area. In addition, the results from the assay of drums currently in retrievable storage at the RWMC support this conclusion. The matrices include waste that will not require monitoring before being loaded into a drum, such as the following:

- Soils
- Sludge material
- Plastics used for contamination control purposes
- Drum remnants.

Currently, other materials (e.g., cemented HEPA filters, intact HEPA filters, HEPA filter media, materials that are indistinguishable from HEPA filter media, graphite molds, chunks of graphite molds larger than approximately 2 in. in diameter, and unknown containerized waste that has the potential to contain an unsafe amount of plutonium) will be fissile monitored before being placed in a waste drum. From an operational standpoint, not creating overloaded drums is highly desirable because of the difficulty associated with repackaging operations. This is especially true in waste matrices that, if overloaded with fissile material, would lend themselves to the formation of a critical system more readily if highly moderated.

Some packaging without monitoring, as described above, will be allowed because of the expected low fissile loading and the composition of the specific waste matrices. Fissile monitoring is not required because of the low expected fissile masses of these waste matrices and the unrealistic, high fissile masses required for criticality to occur in such waste matrices.

In addition, a criticality alarm system at the project site will provide coverage to mitigate the consequences of a criticality accident for both the waste retrieval area and the PGS.

The types of waste matrices expected to be retrieved and repackaged during project activities lead to the conclusion that the formation of a critical system will be a very low-probability event. However, a criticality scenario cannot be dismissed as incredible within the waste retrieval area and PGS because controls do not exist on the amount of fissile material present. Controls will be implemented prohibiting the disturbance of fissile masses in the presence of an unsafe amount of moderating material, in addition to fissile monitoring controls on certain waste types within the PGS to address the postulated criticality scenarios.

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Appendix A

**Sample of Monte Carlo N-Particle Transport Code
Input Listings**

Appendix A

Sample of Monte Carlo N-Particle Transport Code Input Listings

This appendix contains examples of the Monte Carlo N-Particle Transport Code input listings for various computational models used in this criticality safety evaluation for the OU 7-10 Glovebox Excavator Method Project.

Case soil3b:

Transfer cart modeled with 30 g/L PuO₂ in fully saturated soil, full reflection around the transfer cart with fully saturated soil.

Case soil3b - Subsurface Disposal Area (SDA) PuO₂ and H₂O in soil

```
c
c Water Saturated Soil as Reflector
c
c 30 g/L PuO2 dispersed homogenously throughout the volume of the
c transfer cart.
c
c Pu modelled as 95% Pu239 5% Pu240
c H/Pu Ratio 422.32
c
1 1 8.1249-02 -1 +2 -3 +4 -5 +6 u=1 $ PuO2, H2O, Soil
2 2 8.1049-02 +1:-2:+3:-4:+5:-6 u=1 $ Water reflector
3 0 -7 +8 -9 +10 -11 +12 fill=1 $ Boundary of Reflector
4 0 +7:-8:+9:-10:+11:-12 $ ziow

1 px 53.34 $ +x Transfer Cart
2 px -53.34 $ -x Transfer Cart
3 py 38.10 $ +y Transfer Cart
4 py -38.10 $ -y Transfer Cart
5 pz 17.78 $ +z Transfer Cart
6 pz 0.0 $ -z Transfer Cart
7 px 103.34 $ +x Refl Boundary
8 px -103.34 $ -x Refl Boundary
9 py 88.10 $ +y Refl Boundary
10 py -88.10 $ -y Refl Boundary
11 pz 67.78 $ +z Refl Boundary
12 pz -50.0 $ -z Refl Boundary

mode n
imp:n 1 1 1 0
c
c
c PuO2 in Saturated Soil in SDA (40% Void Volume Filled w H2O)
m1 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04
20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04
11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05
5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9468-02
94239.55c 6.3321-05 94240.50c 3.3188-06
c
c Saturated Soil in SDA (40% Void Volume Filled w H2O)
m2 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04
20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04
11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05
5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9335-02
c
c Water (0.9982 g/cm3)
m3 1001.50c 2 8016.50c 1
c
kcode 4000 1.0 50 200
c
c Source for Array
ksrcO 0 10
c
print
```

Case drum-741a15:

Single drum containing Series 741 sludge and 15 g/L of PuO₂ dispersed homogeneously throughout drum volume, fully reflected by fully saturated soil.

Case drum_741a15 - Subsurface Disposal Area (SDA) PuO₂ in 741 Sludge

c

c Soil as Reflector

c

c Sludge modelled with an average density of 1.0 g/cm³

c 15 g/L PuO₂ dispersed homogeneously throughout the volume of the

c 55 gal waste drum.

c

c Pu modelled as 95% Pu²³⁹ 5% Pu²⁴⁰

c H/Pu Ratio 1102

c

1 1 6.3313-02 -1 -2 +3 u=1 \$ PuO₂ in sludge

2 4 8.5863-02 (+1:+2:-3) u=1 \$ Carbon steel Drum

3 0 -4 -5 +6 fill=1 u=2 \$ Carbon steel Drum

4 2 8.1049-02 (+4:+5:-6) u=2

5 0 -7 +8 -9 +10 -11 +12 fill=2 \$ Reflector

6 0 +7:-8:+9:-10:+11:-12 \$ ziow

1 cz 28.57 \$ Inside Radius of 55 gal drum

2 pz 42.545 \$ +z Inside Height of 55 gal drum

3 pz -42.545 \$ -z Inside Height of 55 gal dru

4 cz 28.727 \$ Carbon Steel 55 gal drum outer radius

5 pz 42.695 \$ +z Outer Height of 55 gal drum

6 pz -42.695 \$ -z Outer Height of 55 gal drum

7 px 128.57 \$ +x Refl Boundary

8 px -128.57 \$ -x Refl Boundary

9 py 128.57 \$ +y Refl Boundary

10 py -128.57 \$ -y Refl Boundary

11 pz 142.695 \$ +z Refl Boundary

12 pz -142.695 \$ -z Refl Boundary

mode n

imp:n 14r 0

c

c

c PuO₂ in 741 Sludge

m1 14000.50c 2.0630-03 13027.50c 2.0560-04 26000.55c 5.1875-04

20000.50c 4.9993-03 19000.50c 9.4589-05 12000.50c 3.2968-04

11023.50c 4.8768-03 17000.50c 4.0432-04 16032.50c 6.4163-06

7014.50c 2.2069-03 1001.50c 3.4899-02 8016.50c 4.8801-02

6012.50c 4.7461-04 94239.55c 3.1660-05 94240.50c 4.6594-06

c

c Saturated Soil in SDA (40% Void Volume Filled w H₂O)

m2 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04

20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04

11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05

5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9366-02

c

c Water (0.9982 g/cm³)

m3 1001.50c 2 8016.50c 1

c

c Carbon Steel Drum

m4 6000.50c 1.9604-03 26000.55c 8.3903-02

c

kcode 4000 1.0 50 200

c

c Source for Array

ksrcO 0 0

c

print

Case sphere—sludge—25cm:

Sphere of Series 741 sludge and various concentrations of PuO₂ dispersed homogeneously sphere, volume of material in sphere equal to volume of fully loaded drum, fully reflected by fully saturated soil.

Case sphere_sludge_25cm - Subsurface Disposal Area (SDA) PuO₂ and H₂O in soil

c

c Soil as Reflector

c

c 1,500 g Pu²³⁹ in PuO₂ Form dispersed homogeneously throughout the volume of sphere

c 25 cm radius - PuO₂ and Sludge

c

c Volume of PuO₂ is ignored in model

c

c Pu modelled as 95% Pu²³⁹ 5% Pu²⁴⁰

c H/Pu Ratio 636.42

c

1 1 6.338601-02 -1 \$ PuO₂, H₂O, Soil

2 3 8.1049-02 +1 -2 \$ Saturated soil reflector

3 0 +2 \$ ziow

1 so 25.0 \$ Radius of PuO₂ and Sludge

2 so 125.0 \$ 100 cm saturated soil reflector

mode n

imp:n 1 1 0

c

c

c PuO₂ in 741 Sludge

m1 14000.50c 2.0630-03 13027.50c 2.0560-04 26000.55c 5.1875-04

20000.50c 4.9993-03 19000.50c 9.4589-05 12000.50c 3.2968-04

11023.50c 4.8768-03 17000.50c 4.0432-04 16032.50c 6.4163-06

7014.50c 2.2069-03 1001.50c 3.4899-02 8016.50c 4.8850-02

6012.50c 4.7461-04 94239.55c 5.4836-05 94240.50c 2.8861-06

c

c 741 Sludge

m2 14000.50c 2.0630-03 13027.50c 2.0560-04 26000.55c 5.1875-04

20000.50c 4.9993-03 19000.50c 9.4589-05 12000.50c 3.2968-04

11023.50c 4.8768-03 17000.50c 4.0432-04 16032.50c 6.4163-06

7014.50c 2.2069-03 1001.50c 3.4899-02 8016.50c 4.8734-02

6012.50c 1.7461-04

c

c Saturated Soil in SDA (40% Void Volume Filled w H₂O)

m3 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04

20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04

11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05

5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9335-02

c

c Water (0.9982 g/cm³)

m4 1001.50c 2 8016.50c 1

c

kcode 4000 1.0 50 200

c

c Source for Array

ksrcO 0 0

c

print

Case drum_743a20:

Single drum containing Series 743 sludge and 20 g/L of PuO₂ dispersed homogeneously throughout drum volume, fully reflected by fully saturated soil.

Case drum_743a20 - Subsurface Disposal Area (SDA) PuO₂ in 743 Sludge

```
c
c Soil as Reflector
c
c Sludge modelled with an average density of 1.2175 g/cm3
c 20 g/L PuO2 dispersed homogeneously throughout the volume of the
c 55 gal waste drum.
c
c Pu modelled as 95% Pu239 5% Pu240
c H/Pu Ratio 1254.6
c
1 1 9.3138-02 -1 -2 +3 u=1 $ PuO2 in 743 sludge
2 4 8.5863-02 (+1:+2:-3) u=1 $ Carbon steel Drum
3 0 -4 -5 +6 fill=1 u=2 $ Carbon steel Drum
4 2 8.1049-02 (+4:+5:-6) u=2
5 0 -7 +8 -9 +10 -11 +12 fill=2 $ Reflector
6 0 +7:-8:+9:-10:+11:-12 $ ziow

1 cz 28.57 $ Inside Radius of 55 gal drum
2 pz 42.545 $ +z Inside Height of 55 gal drum
3 pz -42.545 $ -z Inside Height of 55 gal dru
4 cz 28.727 $ Carbon Steel 55 gal drum outer radius
5 pz 42.695 $ +z Outer Height of 55 gal drum
6 pz -42.695 $ -z Outer Height of 55 gal drum
7 px 128.57 $ +x Refl Boundary
8 px -128.57 $ -x Refl Boundary
9 py 128.57 $ +y Refl Boundary
10 py -128.57 $ -y Refl Boundary
11 pz 142.695 $ +z Refl Boundary
12 pz -142.695 $ -z Refl Boundary

mode n
imp:n 1 4r 0
c
c
c PuO2 in 741 Sludge
m1 14000.50c 1.9394-03 13027.50c 1.2174-04 26000.55c 2.1650-05
20000.50c 4.4150-03 19000.50c 3.8139-05 12000.50c 3.6688-04
11023.50c 3.8139-03 17000.50c 4.3083-03 1001.50c 3.4899-02
8016.50c 5.6725-03 6012.50c 2.6540-02
94239.55c 4.2214-05 94240.50c 2.2125-06
c
c Saturated Soil in SDA (40% Void Volume Filled w H2O)
m2 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04
20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04
11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05
5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9366-02
c
c Water (0.9982 g/cm3)
m3 1001.50c 2 8016.50c 1
c
c Carbon Steel Drum
m4 6000.50c 1.9604-03 26000.55c 8.3903-02
c
kcode 4000 1.0 50 200
c
c Source for Array
ksrcO 0 0
c
print
```

Case sphere_743sludge_15cm:

Sphere of Series 743 sludge and various concentrations of PuO₂ dispersed homogeneously sphere, volume of material in sphere equal to volume of fully loaded drum, fully reflected by fully saturated soil.

Case sphere_743sludge_15cm - Subsurface Disposal Area (SDA) PuO₂ in 743 Sludge

c

c Saturated Soil as Reflector

c

c 1,500 g Pu239 in PuO₂ Form dispersed homogeneously throughout the volume of sphere

c 15 cm radius - PuO₂ and 743 Sludge

c

c Volume of PuO₂ is ignored in model

c

c Pu modelled as 95% Pu239 5% Pu240

c H/Pu Ratio 208.6

c

1 1 9.380663-02 -1 \$ PuO₂, and 743 Sludge

2 3 8.1049-02 +1 -2 \$ Saturated soil reflector

3 0 +2 \$ ziow

1 so 15.0 \$ Radius of PuO₂ and Sludge

2 so 115.0 \$ 100 cm saturated soil reflector

mode n

imp:n 1 1 0

c

c

c PuO₂ in 743 Sludge

m1 14000.50c 1.9394-03 13027.50c 1.2174-04 26000.55c 2.1650-05

20000.50c 4.4150-03 19000.50c 3.8139-05 12000.50c 3.6688-04

11023.50c 3.8139-03 17000.50c 4.3083-03 1001.50c 3.4899-02

8016.50c 6.1181-03 6012.50c 2.6540-02

94239.55c 2.5387-04 94240.50c 4.3362-05

c

c 743 Sludge

m2 14000.50c 1.9394-03 13027.50c 1.2174-04 26000.55c 2.1650-05

20000.50c 4.4150-03 19000.50c 3.8139-05 12000.50c 3.6688-04

11023.50c 3.8139-03 17000.50c 4.3083-03 1001.50c 3.4899-02

8016.50c 5.5836-03 6012.50c 2.6540-02

c

c Saturated Soil in SDA (40% Void Volume Filled w H₂O)

m3 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04

20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04

11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05

5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9335-02

c

c Water (0.9982 g/cm³)

m4 1001.50c 2 8016.50c 1

c

kcode 4000 1.0 50 200

c

c Source for Array

ksrcO 0 0

c

print

Case drum_soil3a9:

Single drum containing Series 743 sludge and 13 g/L of PuO₂ dispersed homogeneously throughout drum volume, fully reflected by fully saturated soil.

Case drum_soil3a9 - Subsurface Disposal Area (SDA) PuO₂ and H₂O in soil

```
c
c Soil as Reflector
c
c 13 g/L PuO2 dispersed homogeneously throughout the volume of the
c 55 gal waste drum.
c
c Pu modelled as 95% Pu239 5% Pu240
c H/Pu Ratio 974
c
1 1 8.1136-02 -1 -2 +3 u=1 $ PuO2, H2O, Soil
2 4 8.5863-02 (+1:+2:-3) u=1 $ Carbon steel Drum
3 0 -4 -5 +6 fill=1 u=2 $ Carbon steel Drum
4 2 8.1049-02 (+4:+5:-6) u=2
5 0 -7 +8 -9 +10 -11 +12 fill=2 $ Reflector
6 0 +7:-8:+9:-10:+11:-12 $ ziow
```

```
1 cz 28.57 $ Inside Radius of 55 gal drum
2 pz 42.545 $ +z Inside Height of 55 gal drum
3 pz -42.545 $ -z Inside Height of 55 gal dru
4 cz 28.727 $ Carbon Steel 55 gal drum outer radius
5 pz 42.695 $ +z Outer Height of 55 gal drum
6 pz -42.695 $ -z Outer Height of 55 gal drum
7 px 128.57 $ +x Refl Boundary
8 px -128.57 $ -x Refl Boundary
9 py 128.57 $ +y Refl Boundary
10 py -128.57 $ -y Refl Boundary
11 pz 142.695 $ +z Refl Boundary
12 pz -142.695 $ -z Refl Boundary
```

mode n

imp:n 1 4r 0

```
c
c PuO2 in Saturated Soil in SDA (40% Void Volume Filled w H2O)
m1 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04
20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04
11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05
5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9388-02
94239.55c 2.7439-05 94240.50c 4.4381-06
```

```
c
c Saturated Soil in SDA (40% Void Volume Filled w H2O)
m2 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04
20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04
11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05
5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9366-02
```

```
c
c Water (0.9982 g/cm3)
m3 1001.50c 2 8016.50c 1
c
c Carbon Steel Drum
m4 6000.50c 1.9604-03 26000.55c 8.3903-02
c
kcode 4000 1.0 50 200
c
c Source for Array
ksrcO 0 0
c
print
```

Case sphere—soil—25cm:

**Sphere of soil and various concentrations of PuO₂ dispersed homogeneously
sphere, volume of material in sphere equal to volume of fully loaded drum, fully reflected
by fully saturated soil.**

Case sphere_soil_25cm - Subsurface Disposal Area (SDA) PuO₂ and H₂O in soil

c

c Soil as Reflector

c

c 1500 g PuO₂ dispersed homogeneously throughout the volume of sphere

c 25 cm radius - PuO₂ and Soil

c 40% void fraction in soil filled with H₂O

c Volume of PuO₂ is ignored in model

c

c Pu modelled as 95% Pu²³⁹ 5% Pu²⁴⁰

c H/Pu Ratio 487.7

c

1 1 8.122253-02 -1 \$ PuO₂, H₂O, Soil

2 2 8.1049-02 +1 -2 \$ Saturated soil reflector

3 0 +2 \$ ziow

1 so 25.0 \$ Radius of PuO₂ and Soil

2 so 125.0 \$ 100 cm saturated soil reflector

mode n

imp:n 1 1 0

c

c

c PuO₂ in Saturated Soil in SDA (40% Void Volume Filled w H₂O)

m1 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04

20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04

11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05

5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9450-02

94239.55c 5.4836-05 94240.50c 2.8861-06

c

c Saturated Soil in SDA (40% Void Volume Filled w H₂O)

m2 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04

20000.50c 6.3198-04 19000.50c 6.1135-04 12000.50c 4.1109-04

11023.50c 4.2591-04 22000.50c 8.2025-05 25055.50c 4.1108-05

5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9335-02

c

c Water (0.9982 g/cm³)

m3 1001.50c 2 8016.50c 1

c

kcode 4000 1.0 50 200

c

c Source for Array

ksrcO 0 0

c

print

Case soil3a_8in_15gperl_soilrefl:

Rectangular tray of plutonium oxide at 15 g/L in saturated soil fully reflected by saturated soil to envelope transfer cart and drum sizing tray.

Case soil3a_8in_15gperl_soilrefl - Subsurface Disposal Area (SDA) PuO2 and H2O in soil

```
c
c Saturated Soil as Reflector
c
c 15 g/L PuO2 dispersed homogenously throughout the volume of the
c transfer cart.
c
c Pu modelled as 95% Pu239 5% Pu240
c H/Pu Ratio 844.65
c
1 1 8.1149-02 -1 +2 -3 +4 -5 +6 u=1 $ PuO2, H2O, Soil
2 2 8.1049-02 +1:-2:+3:-4:+5:-6 u=1 $ Saturated Soil reflector
3 0 -7 +8 -9 +10 -11 +12 fill=1 $ Boundary of Reflector
4 0 +7:-8:+9:-10:+11:-12 $ ziow

1 px 63.5 $ +x Transfer Cart
2 px -63.5 $ -x Transfer Cart
3 py 78.74 $ +y Transfer Cart
4 py -78.74 $ -y Transfer Cart
5 pz 20.32 $ +z Transfer Cart
6 pz 0.0 $ -z Transfer Cart
7 px 113.5 $ +x Refl Boundary
8 px -113.5 $ -x Refl Boundary
9 py 128.74 $ +y Refl Boundary
10 py -128.74 $ -y Refl Boundary
11 pz 70.32 $ +z Refl Boundary
12 pz -50.0 $ -z Refl Boundary
```

mode n

imp:n 1 1 1 0

```
c
c
c PuO2 in Saturated Soil in SDA (40% Void Volume Filled w H2O)
m1 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04
20000.50c 6.3198-04 19000.50c 6.1135-04 12000.504.1109-04
11023.504.2591-04 22000.508.2025-05 25055.504.1108-05
5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9402-02
94239.553.1660-05 94240.504.6594-06
```

```
c
c Saturated Soil in SDA (40% Void Volume Filled w H2O)
m2 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04
20000.50c 6.3198-04 19000.50c 6.1135-04 12000.504.1109-04
11023.504.2591-04 22000.508.2025-05 25055.504.1108-05
5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9335-02
```

```
c
c Water (0.9982 g/cm3)
m3 1001.50c 2 8016.50c 1
```

```
c
kcode 4000 1.0 50 200
```

```
c
c Source for Array
ksrc 0 0 10
```

```
c
print
```

Case water-I 1g-I_tilt:

Drum-sizing tray of plutonium oxide at 11 g/L in water soil fully reflected by water at a tilted angle to envelope worst case tilt scenario

Case water-I 1g-I_tilt - Subsurface Disposal Area (SDA) PuO2 in H2O

c

c Water as Reflector

c

c 11 g/L PuO2 dispersed homogenously throughout the volume of the

c drum sizing tray.

c

c Pu modelled as 95% Pu239 5% Pu240

c H/Pu Ratio 1589

c

1 1 1.0017-01 -8 -7 -3 +4 -5 +6 -20 \$ PuO2, H2O

2 3 -0.9982 -8 -7 -3 +4 -5 +6 +20 \$ PuO2, H2O

3 3 -0.9982 #1 #2 -9 +10 -11 +12 -13 +14 \$ Water reflector

4 0 +9:-10:+11:-12:+13:-14 \$ ziow

1 px 60.6425 \$ +x Transfer Cart

2 px -60.6425 \$ -x Transfer Cart

3 py 76.2 \$ +y Transfer Cart

4 py -76.2 \$ -y Transfer Cart

5 pz 43.18 \$ +z Transfer Cart

6 pz 0.0 \$ -z Transfer Cart

7 p -33.02 -76.20 0 -33.02 76.20 0 -60.6425 -76.20 45.72 \$ -x Slanted Surface

8 p 33.02 -76.20 0 33.02 76.20 0 60.6425 -76.20 45.72 \$ +x Slanted Surface

9 px 91.1225 \$ +x Refl Boundary

10 px -91.1225 \$ -x Refl Boundary

11 py 106.68 \$ +y Refl Boundary

12 py -106.68 \$ -y Refl Boundary

13 pz 73.66 \$ +z Refl Boundary

14 pz -30.48 \$ -z Refl Boundary

20 p 33.02 -76.20 20.32 -33.02 -76.20 20.32 60.6425 76.20 45.72 \$ z Slanted Surface

mode n

imp:n 1 1 1 0

c

c

c PuO2 in H2O

m1 1001.50c 6.6734-02 8016.50c 3.3416-02

94239.552 3218-05 94240.50 4.2169-06

c

c Saturated Soil in SDA (40% Void Volume Filled w H2O)

m2 14000.50c 1.0034-02 13027.50c 2.2387-03 26000.55c 5.1263-04

20000.50 6.3198-04 19000.50c 6.1135-04 12000.50 4.1109-04

11023.50 4.2591-04 22000.50 8.2025-05 25055.50 4.1108-05

5011.56c 1.3781-05 1001.50c 2.6742-02 8016.50c 3.9335-02

c

c Water (0.9982g/cm3)

m3 1001.50c 2 8016.50c 1

c

kcode 4000 1.0 50 200

c

c Source for Array

ksrc 0 0 10

c

print

Validation Case - Bare_ps1258:

Bare sphere of plutonium nitrate

Case Bare-ps1258 - PuNO₃ Bare Sphere PU-SOL-THERM-021

c

c 39.0 g Pu/l, 1.081 g/cc, 0.4N 65.26g NO₃ 4.57% Pu-240

c

c

1 1 1.0078556-01 -1 u=1 \$ Pu Nitrate

2 2 8.62396-02 +1 -2 u=1 \$304 SS Shell

3 0 #1 #2 -7 +10 u=1

4 2 8.62396-02 #1 #2 +7 -6 +10 u=1

5 0 #1 #2 -9 -10 u=1

6 2 8.62396-02 #1 #2 +9 -8 -10 u=1

7 0 +2 #3 #4 #5 #6 u=1

8 0 -5 fill=1

9 0 +5 \$ ZIOW

1 so 19.3304 \$ Sphere Inner Radius

2 so 19.4523 \$ Sphere Outer Radius

3 px 19.3304 \$ Liquid Level

4 px 0.0 \$ Mid point

5 so 49.4523 \$ Outer surface

6 c/z 0.0 3.811 2.8575 \$ Top Support Tube OD

7 c/z 0.0 3.811 2.6924 \$ Top Support Tube ID

8 cz 2.86 \$ Bottom Tube OD

9 cz 2.555 \$ Bottom Tube ID

10 pz 0.0 \$ Mid point

mode n

imp:n 1 7r 0

c

c

c PuO₂ in H₂O

m1 1001.50c 6.5515-02 8016.50c 3.4538-02

94239.55c 9.3366-05 94240.50c 4.5680-06

94238.50c 5.9197-09 94241.50c 2.7573-07

94242.50c 8.7324-09 7014.50c 6.3382-04

c

c 304L SS

m2 24000.50c 1.7428-02 28000.50c 7.7203-03 26000.55c 5.9355-02

25055.50c 7.7203-03

c

c Water (0.9982 g/cm³)

m3 1001.50c 2 8016.50c 1

c

mtl lwtr.01t \$ S(Alpha, Beta)

c

kcode 4000 1.0 50 200

c

c Source for Array

ksrcO 0 0

c

print

Validation Case - Refl_ps2325:

Reflected sphere of Plutonium Nitrate

Case Refl-ps2325 - PuNO₃ Refl Sphere PU-SOL-THERM-021

c

c 25.2 g Pu/l, 1.060 g/cc, 0.4N 65.26g NO₃ 4.57% Pu-240

c

c

```
1 1 1.0044471-01 -1 -3 u=1 $ Pu Nitrate
2 0 -1 +3 u=1 $Void above solution
3 2 8.62396-02 +1 -2 u=1 $304 SS Shell
4 0 #1 #2 #3 -7 +10 u=l
5 2 8.62396-02 #1 #2 #3 +7 -6 +10 u=1
6 0 #1 #2 #3 -9 -10 u=l
7 2 8.62396-02 #1 #2 #3 +9 -8 -10 u=1
8 3 -0.9982 +2 #4 #5 #6 #7 u=1
9 0 -5 fill=1
10 0 +5 $ ZIOW
```

```
1 so 19.3304 $ Sphere Inner Radius
2 so 19.4523 $ Sphere Outer Radius
3 pz 18.7540 $ Liquid Level
4 px 0.0 $ Mid point
5 so 49.4523 $ Outer surface
6 c/z 0.0 3.811 2.8575 $ Top Support Tube OD
7 c/z 0.0 3.811 2.6924 $ Top Support Tube ID
8 cz 2.86 $ Bottom Tube OD
9 cz 2.555 $ Bottom Tube ID
10 pz 0.0 $Mid point
```

mode n

imp:n 1 8r 0

c

c

c PuO₂ in H₂O

```
m1 1001.50c 6.5486-02 8016.50c 3.4317-02
    94239.55c 6.0329-05 94240.50c 2.9516-06
    94238.50c 3.8250-09 94241.50c 1.7816-07
    94242.50c 5.6425-09 7014.50c 5.7905-04
```

c

c 304L SS

```
m2 24000.50c 1.7428-02 28000.50c 7.7203-03 26000.55c 5.9355-02
    25055.50c 7.7203-03
```

c

c Water (0.9982 g/cm³)

```
m3 1001.50c 2 8016.50c 1
```

c

mtl lwtr.01t \$ S(Alpha, Beta)

c

kcode 4000 1.0 50 200

c

c Source for Array

ksrcO 0 0

c

print

Appendix B

**Excel Spreadsheets—Calculated Inputs
for Computational Models**

Appendix B

Excel Spreadsheets—Calculated Inputs for Computational Model

The spreadsheets in this appendix contain the mathematical calculations to produce the input parameters that were used in the computational models for the OU 7-10 Glovebox Excavator Method Project criticality safety evaluation.

Table B-1. Excel spreadsheet calculations used in transfer cart computational models.

Calculations For GEM Transfer Carts

²³⁹Pu Gram per liter values

MA Pu239(95%) Pu240 (5%)	239 1021	Constituent	wt% in PuO ₂
MA Pu239	239 0521	Pu ²³⁹	0 8379
MA Pu240	240 0538	Pu ²⁴⁰	0 0441
MA Pu239(95%) Pu240 (5%)O ₂	271 1009	O	0 1180
Density of PuO ₂ (g/cm ³)	11 46	Total	1
Volume of transfer cart(l)	14453		

g/L PuO ₂	g/cm ³ PuO ₂	N ^{Pu239}	N ^{Pu240}	N ^O	N ^{Total}	N ^{O Tot}	N ^{Total Overall}	Total Mass PuO ₂ (g)
5	0 005	1.0553E-05	5 5313E-07	2 22131E-05	3 3320E-05	3 9357E-02	8 1083E-02	722 65
6	0 006	12664E-05	6 6375E-07	2 66558E-05	3 9984E-05	3 9362E-02	8 1089E-02	867 18
7	0 007	1.4775E-05	7 7438E-07	3 10984E-05	4 6648E-05	3 9366E-02	8 1096E-02	1011 71
8	0 008	1.6886E-05	8 8500E-07	3 5541 E-05	5 3312E-05	3 9370E-02	8 1103E-02	115624
9	0 009	1.8996E-05	9 9563E-07	3 99836E-05	5 9975E-05	3 9375E-02	8 1109E-02	1300 77
10	0 01	2 1107E-05	11063E-06	4 44263E-05	6 6639E-05	3 9379E-02	8 1116E-02	1445 3
11	0 011	2 3218E-05	1 2169E-06	4 88689E-05	7 3303E-05	3 9384E-02	8 1123E-02	1589 83
12	0 012	2 5328E-05	1.3275E-06	5 33115E-05	7 9967E-05	3 9388E-02	8 1129E-02	1734 36
13	0 013	2 7439E-05	1 4381E-06	5 77541E-05	8 6631 E-05	3 9393E-02	8 1136E-02	1878 89
14	0 014	2 9550E-05	1.5488E-06	6 21968E-05	9 3295E-05	3 9397E-02	8 1143E-02	2023 42
15	0 015	3 1660E-05	1.6594E-06	6 66394E-05	9 9959E-05	3 9402E-02	8 1149E-02	2167 95
16	0 016	3 3771E-05	17700E-06	7 1082E-05	10662E-04	3 9406E-02	8 1156E-02	2312 48
17	0 017	3 5882E-05	1.8806E-06	7 55246E-05	1 1329E-04	3 9410E-02	8 1163E-02	2457 01
18	0 018	3 7992E-05	1 9913E-06	7 99673E-05	1 1995E-04	3 9415E-02	8 1169E-02	2601 54
19	0 019	4 0103E-05	2 1019E-06	8 44099E-05	1 2661 E-04	3 9419E-02	8 1176E-02	2746 07
20	0 02	4 2214E-05	2 2125E-06	8 88525E-05	1.3328E-04	3 9424E-02	8 1183E-02	2890 6
30	0 03	6 3321E-05	3 3188E-06	133279E-04	19992E-04	3 9468E-02	8 1249E-02	4335 9
40	0 04	8 4428E-05	4 4250E-06	1.77705E-04	2 6656E-04	3 9513E-02	8 1316E-02	5781 2
50	0 05	1.0553E-04	5 5313E-06	2 22131E-04	3 3320E-04	3 9557E-02	8 1383E-02	7226 5
60	0 06	12664E-04	6 6375E-06	2 66558E-04	3 9984E-04	3 9601 E-02	8 1449E-02	8671 8
70	0 07	1.4775E-04	7 7438E-06	3 10984E-04	4 6648E-04	3 9646E-02	8 1516E-02	10117 1
80	0 08	1.6886E-04	8 8500E-06	3 5541 OE-04	5 3312E-04	3 9690E-02	8 1582E-02	11562 4
90	0 09	1.8996E-04	9 9563E-06	3 99836E-04	5 9975E-04	3 9735E-02	8 1649E-02	13007 7
100	0 1	2 1107E-04	11063E-05	4 44263E-04	6 6639E-04	3 9779E-02	8 1716E-02	14453
110	0 11	2 3218E-04	1 2169E-05	4 88689E-04	7 3303E-04	3 9824E-02	8 1782E-02	15898 3

Table B-1. (continued)

g/L PuO ₂	HI/Pu Ratio	Grams of ²³⁹ Pu
5	2533.95	605.49
6	2111.62	726.58
7	1809.96	847.68
8	1583.72	968.78
9	1407.75	1089.87
10	1266.97	1210.97
11	1151.79	1332.07
12	1055.81	1453.17
13	974.59	1574.26
14	904.98	1695.36
15	844.65	1816.46
16	791.86	1937.55
17	745.28	2058.65
18	703.87	2179.75
19	666.83	2300.85
20	633.49	2421.94
30	422.32	3632.92
40	316.74	4843.89
50	253.39	6054.86
60	211.16	7265.83
70	181.00	8476.80
80	158.37	9687.77
90	140.77	10898.75
100	126.70	12109.72
110	115.18	13320.69

Table B-1. (continued).

Element	WVF	0	0.1	0.2	0.3	0.4
Si		1.0034E-02	1.0034E-02	1.0034E-02	1.0034E-02	1.0034E-02
Al		2.2387E-03	2.2387E-03	2.2387E-03	2.2387E-03	2.2387E-03
Fe		5.1263E-04	5.1263E-04	5.1263E-04	5.1263E-04	5.1263E-04
Ca		6.3198E-04	6.3198E-04	6.3198E-04	6.3198E-04	6.3198E-04
K		6.1135E-04	6.1135E-04	6.1135E-04	6.1135E-04	6.1135E-04
Mg		4.1109E-04	4.1109E-04	4.1109E-04	4.1109E-04	4.1109E-04
Na		4.2591E-04	4.2591E-04	4.2591E-04	4.2591E-04	4.2591E-04
Ti		8.2025E-05	8.2025E-05	8.2025E-05	8.2025E-05	8.2025E-05
Mn		1.1108E-05	1.1108E-05	1.1108E-05	1.1108E-05	1.1108E-05
B11		1.3781E-05	1.3781E-05	1.3781E-05	1.3781E-05	1.3781E-05
H		0.0000E+00	6.6855E-03	1.3371E-02	2.0056E-02	2.6742E-02
O		2.5964E-02	2.9307E-02	3.2649E-02	3.5992E-02	3.9335E-02
		4.093657E-02	5.096477E-02	6.099297E-02	7.102117E-02	8.104937E-02

Table B-2. Excel spreadsheet calculations used for Series 741 sludge spherical computational models.

PuO₂ in 741 Sludge Calculations

²³⁹Pu(95%) ²⁴⁰Pu(5%) O₂-741 Sludge Mixture

Density of Graphite (g/cm ³)	2.25							
M _A Pu ²³⁹ (95%) Pu ²⁴⁰ (5%)	239.1021							
M _A Pu ²³⁹ (95%) Pu ²⁴⁰ (5%)O ₂	271.1009							
Density of PuO ₂ (g/cm ³)	11.46							
Grams of Pu (g)	1500	200	400	600	800	1000		
Grams of PuO ₂ (g)	1700.74	226.77	453.53	680.30	907.06	1133.83		
Volume of PuO ₂ (cm ³)	148.41	19.79	39.58	59.36	79.15	98.94		
Inside Radius of 55 Gal Drum (cm)	28.57							
Inside Hieght of 55 Gal Drum (cm)	85.09							
Vol of 55 Gal Drum (cm ³)	218197.0512							
Radius of Sludge Sphere (cm)	37.3467							
Radius of PuO ₂ in 741 Sludge(cm)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	37.3467
Vol of PuO ₂ at Radius (cm ³)	523.5988	4188.7902	14137.1669	33510.3216	65449.8469	113097.3355	179594.3800	218194.6815
Vol of 741 Sludge (Vol tot - Vol PuO ₂)	375.1918	4040.3833	13988.7600	33361.9147	65301.4400	112948.9286	179445.9731	218046.2745
	6.8545E-03	8.5681E-04	2.5387E-04	1.0710E-04	5.4836E-05	3.1734E-05	1.9984E-05	1.6449E-05
N ²⁴⁰	3.6076E-04	4.5095E-05	1.3362E-05	5.6369E-06	2.8861E-06	1.6702E-06	1.0518E-06	8.6571E-07
N ^O	1.4430E-02	1.8038E-03	5.3446E-04	2.2548E-04	1.1544E-04	6.6808E-05	4.2071E-05	3.4629E-05
N ^{O Tot}	3.3165E-02	2.0538E-02	1.9269E-02	1.8960E-02	1.8850E-02	1.8801E-02	1.8776E-02	1.8769E-02
N ^{Tot}	8.485853E-02	6.591855E-02	6.401454E-02	6.355106E-02	6.338601E-02	6.331306E-02	6.327595E-02	6.326479E-02
Density of PuO ₂ in 741 Sludge (g/cm ³)	3.24818	0.40602	0.12030	0.05075	0.02599	0.01504	0.00947	0.00779
H/Pu Ratio	5.09	40.73	137.47	325.85	636.42	1099.73	1746.34	2121.68

Table B-2. (continued).

741 Sludge					
Constituent	Avg. Wt. %'s	Norm. wt. %'s	Atomic Mass	Atomic Mass Pres	Atom Density
Al	0.9	0.921	26.9815	0.2486	2.0560E-04
Ca	13	13.306	40.078	5.3328	1.9993E-03
Fe	4.7	4.811	55.845	2.6865	5.1875E-04
K	0.6	0.614	39.0983	0.2401	9.4589E-05
Mg	1.3	1.331	24.305	0.3234	3.2968E-04
Na	7	7.165	22.989	1.6471	1.8768E-03
Si	9.4	9.621	28.0855	2.7022	2.0630E-03
Ga	0	0.000	69.723	0.0000	0.0000E+00
NO3 Compound	7.4	7.574	62.0049	4.6964	
N		5.133	14.0067		2.2069E-03
O		1.954	15.9994		7.3562E-04
C03 Compound	1.7	1.740	60.0089	1.0442	
C		0.348	12.0107		1.7461E-04
O		1.392	15.9994		5.2384E-04
Cl	0.6	0.614	35.4527	0.2177	1.0432E-04
F	0	0.000	18.9984	0.0000	0.0000E+00
PO4 Compound	0	0.000	94.9713	0.0000	
P		0.000	30.9737		0.0000E+00
O		0.000	15.9994		0.0000E+00
SO4 Compound	0.1	0.102	96.0636	0.0983	
S		0.034	32.066		6.4163E-06
O		0.068	15.9994		2.5665E-05
H2O Compound	51	52.201	18.0152	9.4040	
H		5.841	1.00794		3.4899E-02
O		46.360	15.9994		1.7449E-02
O Total					1.8734E-02
	97.7	108.930		28.6413	6.3213E-02

Table B-3. Excel Spreadsheet calculations used for Series 743 sludge spherical computational models.

PuO₂ in 743 Sludge Spherical Calculations

²³⁹Pu(95%) ²⁴⁰Pu(5%) O₂-743 Sludge Mixture

Density of Graphite (g/cm ³)	2.25							
M _A Pu ²³⁹ (95%) Pu ²⁴⁰ (5%)	239.1021							
M _A Pu ²³⁹ (95%) Pu ²⁴⁰ (5%)O ₂	271.1009							
Density of PuO ₂ (g/cm ³)	11.46							
Grams of Pu (g)	1500	200	400	600	800	1000		
Grams of PuO ₂ (g)	1700.74	226.77	453.53	680.30	907.06	1133.83		
Volume of PuO ₂ (cm ³)	148.41	19.79	39.58	59.36	79.15	98.94		
Inside Radius of 55 Gal Drum (cm)	28.57							
Inside Hieght of 55 Gal Drum (cm)	85.09							
Vol of 55 Gal Drum (cm ³)	218197.0512							
Radius of Sludge Sphere (cm)	37.3467							
Radius of PuO ₂ in 743 Sludge(cm)	5.0	10.0	15.0	20.0	25.0	30.0	35.0	37.3467
Vol of PuO ₂ at Radius (cm ³)	523.5988	4188.7902	14137.1669	33510.3216	65449.8469	113097.3355	179594.3800	218194.6815
Vol of 743 Sludge (Vol tot - Vol PuO ₂)	375.1918	4040.3833	13988.7600	33361.9147	65301.4400	112948.9286	179445.9731	218046.2745
N ²⁴⁰	6.8545E-03	8.5681E-04	2.5387E-04	1.0710E-04	5.4836E-05	3.1734E-05	1.9984E-05	1.6449E-05
N ^O	3.6076E-04	4.5095E-05	1.3362E-05	5.6369E-06	2.8861E-06	1.6702E-06	1.0518E-06	8.6571E-07
N ^{O Tot}	1.4430E-02	1.8038E-03	5.3446E-04	2.2548E-04	1.1544E-04	6.6808E-05	4.2071E-05	3.4629E-05
N ^{Tot}	2.0014E-02	7.3874E-03	6.1181E-03	5.8091E-03	5.6991E-03	5.6504E-03	5.6257E-03	5.6182E-03
N	1.146506E-01	9.571064E-02	9.380663E-02	9.334315E-02	9.317810E-02	9.310515E-02	9.306804E-02	9.305688E-02
Density of PuO ₂ in 741 Sludge (g/cm ³)	3.24818	0.40602	0.12030	0.05075	0.02599	0.01504	0.00947	0.00779
H/Pu Ratio	7.73	61.81	208.62	494.51	965.84	1668.97	2650.26	3219.89

Table B-3. (continued)

Mixture Density(g/cm ³)		1.2175			
Constituent		Atomic Mass	Comp. Norm wt. %	Overall Wt%	Atom Density
Micro-cel E					
SiO ₂		60.0843	55.95	28.407	
	Si	28.0855	26.1530	7.4293	1.9394E-03
	O	15.9994	29.7970	8.4644	3.8787E-03
Al ₂ O ₃		101.9602	2.98		
	Al	26.981	1,5772	0.4480	1.2174E-04
	O	15.9994	1,4028	0.3985	1.8261E-04
Fe ₂ O ₃		159.688	0.830		
	Fe	55.845	0.5805	0.1649	2.1650E-05
	O	15.9994	0.2495	0.0709	3.2475E-05
CaO		56.077	38.100		
	Ca	40.078	27.2297	7.7351	1.4150E-03
	O	15.9994	10.8703	3.0879	1.4150E-03
MgO		40.304	0.710		
	Mg	24.305	0.4282	0.1216	3.6688E-05
	O	15.9994	0.2818	0.0801	3.6688E-05
Na ₂ O + K ₂ O		156.175	1.430		
	Na	22.9897	0.4210	0.1196	3.8139E-05
	O	15.9994	0.1465	0.0416	1.9070E-05
	K	39.0983	0.7160	0.2034	3.8139E-05
	O	15.9994	0.1465	0.0416	1.9070E-05
Teaxco Regal Oil				48.995	
C ₂₅ H ₅₂ (C _n H _{2n+2})		352.6783			
	C	12.0107		41.7140	2.5463E-02
	H	1,0079		7.2810	5.2963E-02
Carbon Tetrachloride				22.598	
CCl ₄		153.8215			
	C	12.0107		1.7645	1.0771E-03
	Cl	35.4527		20.8335	4.3083E-03
					9.3005E-02 N ^O Tot Sludge
					5.5836E-03
					N ^C Tot Sludge
					2.6540E-02
					N ^{Tot} Sludge
					9.3005E-02

Table B-4. Excel spreadsheet calculations used for Series 743 sludge in drum computational models

Calculations For Plutonium Oxide in 743 Sludge Drums - OU 7-10 Projects

²³⁹Pu Gram per liter values

MA Pu239(95%) Pu240 (5%)	239.1021	Pu ²³⁹	0.8379
MA Pu239	239.0521	Pu ²⁴⁰	0.0441
MA Pu240	240.0538	O	0.1180
MA Pu239(95%) Pu240 (5%)O2	271,1009	Total	1
Density of PuO2 (g/cm3)	11.46		
Inside Radius 55 Gal Drum (cm)	28.57		
Inside Ht 55 Gal Drum (cm)	85.09		
Vol of 55 Gal Drum(cm3)	218197.0512		

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g/L PuO ₂	g/cm ³ PuO ₂	N ^{Pu239}	N ^{Pu240}	N ^O	N ^{PuO2 Total}	N ^{O Total Overall}	N ^{Total Overall}
5	0.005	1.0553E-05	5.5313E-07	2.22131E-05	3.3320E-05	5.6058E-03	9.3038E-02
6	0.006	1.2664E-05	6.6375E-07	2.66558E-05	3.9984E-05	5.6103E-03	9.3045E-02
7	0.007	1.4775E-05	7.7438E-07	3.10984E-05	4.6648E-05	5.6147E-03	9.3052E-02
8	0.008	1.6886E-05	8.8500E-07	3.5541E-05	5.3312E-05	5.6192E-03	9.3058E-02
9	0.009	1.8996E-05	9.9563E-07	3.99836E-05	5.9975E-05	5.6236E-03	9.3065E-02
10	0.01	2.1107E-05	1.1063E-06	4.44263E-05	6.6639E-05	5.6280E-03	9.3072E-02
11	0.011	2.3218E-05	1.2169E-06	4.88689E-05	7.3303E-05	5.6325E-03	9.3078E-02
12	0.012	2.5328E-05	1.3275E-06	5.33115E-05	7.9967E-05	5.6369E-03	9.3085E-02
13	0.013	2.7439E-05	1.4381E-06	5.77541E-05	8.6631E-05	5.6414E-03	9.3092E-02
14	0.014	2.9550E-05	1.5488E-06	6.21968E-05	9.3295E-05	5.6458E-03	9.3098E-02
15	0.015	3.1660E-05	1.6594E-06	6.66394E-05	9.9959E-05	5.6502E-03	9.3105E-02
16	0.016	3.3771E-05	1.7700E-06	7.1082E-05	1.0662E-04	5.6547E-03	9.3112E-02
17	0.017	3.5882E-05	1.8806E-06	7.55246E-05	1.1329E-04	5.6591E-03	9.3118E-02
18	0.018	3.7992E-05	1.9913E-06	7.99673E-05	1.1995E-04	5.6636E-03	9.3125E-02
19	0.019	4.0103E-05	2.1019E-06	8.44099E-05	1.2661E-04	5.6680E-03	9.3132E-02
20	0.02	4.2214E-05	2.2125E-06	8.88525E-05	1.3328E-04	5.6725E-03	9.3138E-02
30	0.03	6.3321E-05	3.3188E-06	1.33279E-04	1.9992E-04	5.7169E-03	9.3205E-02
40	0.04	8.4428E-05	4.4250E-06	1.77705E-04	2.6656E-04	5.7613E-03	9.3271E-02
50	0.05	1.0553E-04	5.5313E-06	2.22131E-04	3.3320E-04	5.8057E-03	9.3338E-02
60	0.06	1.2664E-04	6.6375E-06	2.66558E-04	3.9984E-04	5.8502E-03	9.3405E-02
70	0.07	1.4775E-04	7.7438E-06	3.10984E-04	4.6648E-04	5.8946E-03	9.3471E-02
80	0.08	1.6886E-04	8.8500E-06	3.55410E-04	5.3312E-04	5.9390E-03	9.3538E-02
90	0.09	1.8996E-04	9.9563E-06	3.99836E-04	5.9975E-04	5.9834E-03	9.3605E-02
100	0.1	2.1107E-04	1.1063E-05	4.44263E-04	6.6639E-04	6.0279E-03	9.3671E-02
Mixture Density(g/cm ³)	1.2175						

Table B-4. (continued)

g/L PuO ₂	Total Mass PuO ₂ (g)	Total Mass ²³⁹ Pu (g)	HIPu Ratio
5	1090.99	914.10	5018.50
6	1309.18	1096.92	4182.09
7	1527.38	1279.74	3584.65
8	1745.58	1462.56	3136.57
9	1963.77	1645.38	2788.06
10	2181.97	1828.21	2509.25
11	2400.17	2011.03	2281.14
12	2618.36	2193.85	2091.04
13	2836.56	2376.67	1930.19
14	3054.76	2559.49	1792.32
15	3272.96	2742.31	1672.83
16	3491.15	2925.13	1568.28
17	3709.35	3107.95	1476.03
18	3927.55	3290.77	1394.03
19	4145.74	3473.59	1320.66
20	4363.94	3656.41	1254.63
30	6545.91	5484.62	836.42
40	8727.88	7312.82	627.31
50	10909.85	9141.03	501.85
60	13091.82	10969.23	418.21
70	15273.79	12797.44	358.46
80	17455.76	14625.64	313.66
90	19637.73	16453.85	278.81
100	21819.71	18282.05	250.93

Table B-4. (continued)

Constituent	Atomic Mass	Comp. Norm wt. %	Overall Wt%	Atom Density	
Micro-cel E					
SiO ₂	60.0843	55.95	28.407		
Si	28.0855	26.1530	7.4293	1.9394E-03	
O	15.9994	29.7970	8.4644	3.8787E-03	
Al ₂ O ₃	101.9602	2.98			
Al	26.981	1.5772	0.4480	1.2174E-04	
O	15.9994	1.4028	0.3985	1.8261E-04	
Fe ₂ O ₃	159.688	0.830			
Fe	55.845	0.5805	0.1649	2.1650E-05	
O	15.9994	0.2495	0.0709	3.2475E-05	
CaO	56.077	38.100			
Ca	40.078	27.2297	7.7351	1.4150E-03	
O	15.9994	10.8703	3.0879	1.4150E-03	
MgO	40.304	0.710			
Mg	24.305	0.4282	0.1216	3.6688E-05	
O	15.9994	0.2818	0.0801	3.6688E-05	
Na ₂ O + K ₂ O	156.175	1.430			
Na	22.9897	0.4210	0.1196	3.8139E-05	
O	15.9994	0.1465	0.0416	1.9070E-05	
K	39.0983	0.7160	0.2034	3.8139E-05	
O	15.9994	0.1465	0.0416	1.9070E-05	
Teaxco Regal Oil			48.995		
C ₂₅ H ₅₂ (C _n H _{2n+2})	352.6783				
C	12.0107		41.7140	2.5463E-02	
H	1.0079		7.2810	5.2963E-02	
Carbon Tetrachloride			22.598		
CCl ₄	153.8215				
C	12.0107		1.7645	1.0771E-03	
Cl	35.4527		20.8335	4.3083E-03	
				9.3005E-02 N ^O Tot Sludge	5.5836E-03
				N ^C Tot Sludge	2.6540E-02
				N ^{Tot} Sludge	9.3005E-02

Table B-5. Excel spreadsheet calculations used for Series 741 sludge in drum computational models.

Calculations For Plutonium Oxide in 741 Sludge Drums - OU 7-10 Projects

²³⁹Pu Gram per liter values

MA Pu239(95%) Pu240 (5%)	239 1021	Pu ²³⁹	0 8379
MA Pu239	239 0521	Pu ²⁴⁰	0 0441
MA Pu240	240 0538	O	0 1180
MA Pu239(95%) Pu240 (5%)O2	271 1009	Total	1
Density of PuO2 (g/cm3)	11 46		
Inside Radius 55 Gal Drum (cm)	28 57		
Inside Ht 55 Gal Drum (cm)	85 09		
Vol of 55 Gal Drum (cm3)	218197 0512		

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g/L PuO ₂	g/cm ³ PuO ₂	N ^{Pu239}	N ^{Pu240}	N ^O	N ^{PuO2Total}	N ^{O Total Overall}	N ^{Total Overall}
5	0 005	1.0553E-05	5 5313E-07	2 22131E-05	3 3320E-05	1.8757E-02	6 3246E-02
6	0 006	1.2664E-05	6 6375E-07	2 66558E-05	3 9984E-05	1 8761E-02	6 3253E-02
7	0 007	1.4775E-05	7 7438E-07	3 10984E-05	4 6648E-05	1.8765E-02	6 3259E-02
8	0 008	1.6886E-05	8 8500E-07	3 5541E-05	5 3312E-05	1.8770E-02	6 3266E-02
9	0 009	1.8996E-05	9 9563E-07	3 99836E-05	5 9975E-05	1.8774E-02	6 3273E-02
10	0 01	2 1107E-05	11063E-06	4 44263E-05	6 6639E-05	1.8779E-02	6 3279E-02
11	0 011	2 3218E-05	1 2169E-06	4 88689E-05	7 3303E-05	1.8783E-02	6 3286E-02
12	0 012	2 5328E-05	1.3275E-06	5 33115E-05	7 9967E-05	1.8788E-02	6 3293E-02
13	0 013	2 7439E-05	1 4381E-06	5 77541E-05	8 6631E-05	1.8792E-02	6 3299E-02
14	0 014	2 9550E-05	1.5488E-06	6 21968E-05	9 3295E-05	1.8797E-02	6 3306E-02
15	0 015	3 1660E-05	1.6594E-06	6 66394E-05	9 9959E-05	1 8801E-02	6 3313E-02
16	0 016	3 3771E-05	17700E-06	7 1082E-05	10662E-04	1.8805E-02	6 3319E-02
17	0 017	3 5882E-05	1.8806E-06	7 55246E-05	1 1329E-04	1.8810E-02	6 3326E-02
18	0 018	3 7992E-05	19913E-06	7 99673E-05	1 1995E-04	1.8814E-02	6 3333E-02
19	0 019	4 0103E-05	2 1019E-06	8 44099E-05	1 2661E-04	1.8819E-02	6 3339E-02
20	0 02	4 2214E-05	2 2125E-06	8 88525E-05	1.3328E-04	1.8823E-02	6 3346E-02
30	0 03	6 3321E-05	3 3188E-06	133279E-04	19992E-04	1.8868E-02	6 3413E-02
40	0 04	8 4428E-05	4 4250E-06	1.77705E-04	2 6656E-04	1.8912E-02	6 3479E-02
50	0 05	1.0553E-04	5 5313E-06	2 22131E-04	3 3320E-04	1.8957E-02	6 3546E-02
60	0 06	1.2664E-04	6 6375E-06	2 66558E-04	3 9984E-04	1 9001E-02	6 3613E-02
70	0 07	1.4775E-04	7 7438E-06	3 10984E-04	4 6648E-04	1.9045E-02	6 3679E-02
80	0 08	1.6886E-04	8 8500E-06	3 55410E-04	5 3312E-04	19090E-02	6 3746E-02
90	0 09	1.8996E-04	9 9563E-06	3 99836E-04	5 9975E-04	1 9134E-02	6 3813E-02
100	0 1	2 1107E-04	11063E-05	4 44263E-04	6 6639E-04	1 9179E-02	6 3879E-02

Table B-5. (continued)

g/L PuO ₂	Total Mass PuO ₂ (g)	Total Mass ²³⁹ Pu (g)	HiPu Ratio
5	1090.99	914.10	3306.84
6	1309.18	1096.92	2755.70
7	1527.38	1279.74	2362.03
8	1745.58	1462.56	2066.77
9	1963.77	1645.38	1837.13
10	2181.97	1828.21	1653.42
11	2400.17	2011.03	1503.11
12	2618.36	2193.85	1377.85
13	2836.56	2376.67	1271.86
14	3054.76	2559.49	1181.01
15	3272.96	2742.31	1102.28
16	3491.15	2925.13	1033.39
17	3709.35	3107.95	972.60
18	3927.55	3290.77	918.57
19	4145.74	3473.59	870.22
20	4363.94	3656.41	826.71
30	6545.91	5484.62	551.14
40	8727.88	7312.82	413.35
50	10909.85	9141.03	330.68
60	13091.82	10969.23	275.57
70	15273.79	12797.44	236.20
80	17455.76	14625.64	206.68
90	19637.73	16453.85	183.71
100	21819.71	18282.05	165.34

Table B-5. (continued).

Constituent	Avg. Wt. %'s	Normalized wt. %'s	Atomic Mass	Atomic Mass Present	Atom Density
Al	0.9	0.921	26.9815	0.2486	2.0560E-04
Ca	13	13.306	40.078	5.3328	1.9993E-03
Fe	4.7	4.811	55.845	2.6865	5.1875E-04
K	0.6	0.614	39.0983	0.2401	9.4589E-05
Mg	1.3	1.331	24.305	0.3234	3.2968E-04
Na	7	7.165	22.989	1.6471	1.8768E-03
Si	9.4	9.621	28.0855	2.7022	2.0630E-03
Ga	0	0.000	69.723	0.0000	0.0000E+00
NO ₃ Compound	7.4	7.574	62.0049	4.6964	
N		5.133	14.0067		2.2069E-03
O		1.954	15.9994		7.3562E-04
CO ₃ Compound	1.7	1.740	60.0089	1.0442	
C		0.348	12.0107		1.7461E-04
O		1.392	15.9994		5.2384E-04
Cl	0.6	0.614	35.4527	0.2177	1.0432E-04
F	0	0.000	18.9984	0.0000	0.0000E+00
PO ₄ Compound	0	0.000	94.9713	0.0000	
P		0.000	30.9737		0.0000E+00
O		0.000	15.9994		0.0000E+00
SO ₄ Compound	0.1	0.102	96.0636	0.0983	
S		0.034	32.066		6.4163E-06
O		0.068	15.9994		2.5665E-05
H ₂ O Compound	51	52.201	18.0152	9.4040	
H		5.841	1.00794		3.4899E-02
O		46.360	15.9994		1.7449E-02
O _{Total}					1.8734E-02
	97.7	108.930		28.6413	6.3213E-02

Appendix C

Subsurface Disposal Area Soil Information

Appendix C

Subsurface Disposal Area Soil Information

The tables in this appendix show the soil composition and input parameters used in the computational models for the OU 7-10 Glovebox Excavator Method Project criticality safety evaluation.

Table C-1. Analysis of soil sample from the spreading areas^a at the Idaho National Engineering and Environmental Laboratory.

Oxide	Composition (wt%)
SiO ₂	62.60
Al ₂ O ₃	11.85
Fe ₂ O ₃	4.25
CaO	3.68
K ₂ O	2.99
MgO	1.72
Na ₂ O	1.37
TiO ₂	0.68
MnO ₂	0.10
BaO	0.09
ZrO ₂	0.05
B ₂ O ₃	0.05
NiO	0.04
SrO	0.02
Cr ₂ O ₃	0.02
Total oxide	89.51
Moisture	7.5

a. Data taken from Callow et al. (1991)

Table C-2. Analysis of normalized soil sample from the spreading areas at the Idaho National Engineering and Environmental Laboratory.

Oxide	Composition (wt%)
SiO ₂	69.936
Al ₂ O ₃	13.239
Fe ₂ O ₃	4.748
CaO	4.111
K ₂ O	3.340
MgO	1.922
Na ₂ O	1.531
TiO ₂	0.760
MnO ₂	0.112
BaO	0.101
ZrO ₂	0.056
B ₂ O ₃	0.056
NiO	0.044
SrO	0.022
Cr ₂ O ₃	0.022
Total oxide	100.0

Table C-3. Compositions of soil from the Subsurface Disposal Area at the Idaho National Engineering and Environmental Laboratory.

Description	Element	Atomsharn-cm
Wet soil	Si	1.0034E-02
	Al	2.2387E-03
	Fe	5.1263E-04
	Ca	6.3198E-04
	K	6.1135E-04
	Mg	4.1109E-04
	Na	4.2591E-04
	Ti	8.2025E-05
	Mn	1.1108E-05
	B-11	1.3781E-05
	H	2.6742E-02
	O	3.9335E-02
Dry soil	Si	1.0034E-02
	Al	2.2387E-03
	Fe	5.1263E-04
	Ca	6.3198E-04
	K	6.1135E-04
	Mg	4.1109E-04
	Na	4.2591E-04
	Ti	8.2025E-05
	Mn	1.1108E-05
	B-11	1.3781E-05
	O	2.5964E-02


Table C-4. Number densities used for cellulose ($C_6H_{10}O_5$ $\rho_{\text{dens}} = 1.45 \text{ g/cm}^3$) material in the MCNP (RSIC 1997) code models.

Element	Nuclide Identification	Number Density (atomshn-cm)
Carbon	6012.50c	3.2310-02
Hydrogen	1001.50c	5.3851-02
Oxygen	8016.50c	2.6925-02

Table C-5. Average composition of Series 741 and 742 sludge matrices.

Constituent	Series 741 Composition (wt%)	Series 742 Composition (wt%)
Al	0.9	1.0
Ca	13.0	12.2
Fe	4.7	4.9
K	0.6	—
Mg	1.3	1.8
Na	7.0	10.0
Si	9.4	—
NO ₃	7.4	8.1
CO ₃	1.7	0.6
Cl	0.6	1.5
SO ₄	0.1	0.14
H ₂ O	51.0	60.0
Total composition	97.7	100.0

Table C-6. Composition of Micro-Cel E used in Series 743 sludge matrices.



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Technical Data

MICRO-CEL® E

TYPICAL PHYSICAL PROPERTIES

Color	Gray to buff
Appearance	Fine Powder
Description	Synthetic Calcium Silicate
Crystalline Silica as Quartz %	<0.1
Screen Analysis	6.0
+325 Mesh, %	550.0
Water Absorption, % by weight	420.0
Oil Absorption	2.6
Specific Gravity	5.4
Loose Weight, lb. ft ³	8.4
pH 10% Slurry	5.5
Moisture, % H ₂ O as shipped	1.55
Refractive Index	120.0
BET Surface Area, m ² /g	60.0
Brightness Photovolt, Blue Light	18.0
d50, Cilas Granulometer, Microns	

TYPICAL CHEMICAL ANALYSIS, WEIGHT %

SiO ₂	47.0
Al ₂ O ₃	2.5
Fe ₂ O ₃	0.7
CaO	32.0
MgO	0.6
Na ₂ O + K ₂ O	1.2
Total LOI	16.0

The physical or chemical properties of Celite® products represent typical, average values obtained in accordance with generally accepted test methods and are subject to normal manufacturing variations. They are supplied as a technical service and are subject to change without notice.
 Technical data shown above are considered accurate and reliable; however, no guarantee is given nor intended. For important health & safety information, please refer to MSDS, a World Minerals Company.

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